MODELING UPS AND ENHANCING THE CAPABILITY BY INTEGRATING RENEWABLE SOURCES

ARIJIT MOJUMDER	10321056
MD. RAISUL HAQUE RAHAT	10321055
MD. ABDUR RAHIM KHAN	09221219
AJAZ AHAMED	10321054

Department of Electrical and Electronic Engineering

December, 2014

BRAC University, Dhaka, Bangladesh

Declaration

We hereby declare that this thesis is based on the results found by ourselves. Materials of work found by other researchers are mentioned by reference.

……………………………….

Signature of the Supervisor

Date:

Acknowledgement

With deep sense of gratitude we express our sincere thanks to our supervisor, Amina Hasan Abedin, Assistant Professor, BRAC University for her guidance in carrying out this work under her supervision, encouragement and cooperation .We are also thankful to the department for their full cooperation.

ABSTRACT

Power outage or power line disturbances have detrimental effect on the operation of critical loads like computer controlling important process or medical equipment. The study of power line disturbances were done in the first phase of the thesis. Uninterruptable Power Supply (UPS) is one of the means to provide back up during disturbances (like overvoltage, under-voltage, sags or swells) and outage. PS provides voltage regulation during power line disturbances and backup power during outage. Study on different UPS construction and range of operation had been completed in the second phase of this thesis. In the UPS there is a rechargeable battery, which supplies power to the load when the power supply is cut off for limited time period. Research papers on renewable energy shows significant improvement of UPS capacity if fuel cells are used in parallel with the battery backup. When the essential load exceeds maximum limit provided by battery, the fuel cell stack then can provide additional power to the extra load. As a result the limited capacity of the battery is possible to overcome by introducing fuel cells in case of excess demand .Study on fuel cell and its promising feature to enhance the UPS capacity is also the part of the thesis.

TABLE OF CONTENT

Chapter 3 Model of UPS

Chapter 4 Boost Converter

Chapter 5 Integrating Boost converter with Inverter

Chapter 6 Conclusion

*****All simulation are done by Power Simulation (PSIM) Software**

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Introduction

UPS (Uninterruptible Power Supply) also called Continuous power supply. The primary purpose of a UPS is to provide conditioned, continuous power to its load during disturbances like overvoltage, under-voltage, sags or swells. Another UPS function that is of growing importance in today's market is system integration, or the ability to communicate over a network to facilitate the monitoring and orderly shutdown of loads. It gives backup to the load 15 to 20 min; it depends on the battery capacity. A good UPS has low THD (Total Harmonic Distortion) and clean output voltage for both linear and non linear loads with high efficiency. On the other hand an ideal UPS should have low THD, zero switching time from normal to backup mode and vice versa , unity power factor(PF), low EMI (Electromagnetic Interference), low maintenance, low cost. As a result it is becoming popular now days, a system that can keep the information and data from being destroyed.

As to the backup and emergency power applications, we normally use batteries in the system for backup but batteries have some problems for maintenance, size and pollution. We also face problem with diesel generator for noise, emission and start up.

We can easily avoid these problems. We can use Fuel cell, a new era in modern science. Low cost technology with unique performance, instant starts capability, low temperature performance. The most promising Fuel cell technology is PEMFC (Proton Exchange Membrane Fuel Cell) where hydrogen is used as fuel. In the system we can combine use small capacity battery and fuel cell to give backup to critical loads. Here PEMFC is applied as the main source and battery is connected as the auxiliary source in the UPS, so that the main pressure on the battery could be reduced.

1.2 Power Quality

Power Quality as a term is often defined as the electrical network's (grid's) ability to supply a clean and stable power flow acting as a perfect power supply that is always available, it has a pure noise-free sinusoidal wave shape, and is always within voltage and frequency tolerances, that means the concept of powering and grounding sensitive electronic equipment.

Poor power quality is related to electricity that does not have the necessary characteristics such as voltage and frequency stability that is needed for electrical equipment to function correctly. Poor power quality can take several forms and have several characteristics.

In the beginning, electrical machines and devices were crude and they consumed large amounts of electricity and performed quite well. The machines were conservatively designed with cost concerns only secondary to performance concern. Now the industrial age led to the need for products to be economically ready for action, which meant that electrical machines were becoming smaller and more efficient and were designed without performance limits. At the same time, other factors were coming into play [1].

Increased demands for electricity created general power generation and distribution grids. Today, electrical utilities are no longer independently operated unit; they are part of a large network of utilities joined together in a complex grid. The combination of these factors has created electrical systems requiring power quality. Two identical devices or pieces of equipment might react differently to the same power quality parameters due to differences in their manufacturing or component tolerance [1].

1.3 Power Quality Terminology

Inrush current: When electrical equipment is first turned on, large current flows that exceeds the steady state current value.

Noise: A disturbance of the smooth flow of electricity in the form of electro-magnetic interference (EMI) or radio frequency interference (RFI). Common sources of noise are motors and electronic devices. Noise can affect performance of electrical equipment. In short it is unwanted electrical signal that produce undesirable effect in the circuit.

Swell or Surge: Voltage exceeds the nominal voltage for one second to one minute. A common cause is high power equipment shutting off.

Sag or under voltage: voltage sag is a short duration reduction in voltage which can be caused by a short circuit, overload or starting of electric motors. Voltage sag happens when the rms voltage decreases between 10 and 90 percent of nominal voltage for one-half cycle to one minute.

Current harmonics: Distortions of the normal sine wave form of the AC, electricity provided by utility at 60Hz or cycles per second. Some types of electricity using equipment cause harmonics by distorting the current wave form. Harmonics can cause voltage distortion and in a three phase system harmonics may cause overheating of neutral line which can lead to damage or fire.

Power factor: Ratio of the total active power (watts) to the total apparent power (volt-amperes) of the composite wave, including all harmonic frequency components. Due to harmonic frequency components, the total power factor is less than the displacement power factor, as the presence of harmonics tends to increase the displacement between the composite voltage and current waveforms [1].

1.4 Power Quality Issues

The concept of good and bad power depends on the end user.

Power frequency disturbances are low-frequency phenomena that result in voltage sags or swells. These may be source or load generated due to faults or switching operations in a power system [1].

Power system transients are fast, short-duration events that produce distortions such as notching, ringing, and impulse.

Power System harmonics are low-frequency phenomena characterized by waveform distortion, which introduces harmonic frequency components. Voltage and current harmonics have undesirable effects on power system operation and power system components. In some instances, interaction between the harmonics and the power system parameters (*R*–*L*–*C*) can cause harmonics to multiply with severe consequences [1].

The subject of **grounding and bonding** is one of the more critical issues in power quality studies. The fundamental objective of grounding is safety, and nothing that is done in an electrical system should compromise the safety of people who work in the environment; The second objective of grounding and bonding is to provide a low-impedance path for the flow of fault current in case of a ground fault so that the protective device could isolate the faulted circuit from the power source. The third use of grounding is to create a ground reference plane for sensitive electrical equipment [1].

Power factor is included for the sake of completing the power quality discussion. In some cases, low power factor is responsible for equipment damage due to component overload.

1.5 Function of UPS

A UPS can solve many PQ problems. A UPS provides a finite source of electrical power to support selected critical loads during a loss of normal power. This backup time ranges from seconds to hours. Nearly every UPS offers power conditioning and overvoltage protection. Beyond protection from sags, surges, and loss of power, a UPS can provide power quality protection and enhancement in several ways.

1.6 Fuel cell

A new dimension in modern science is using fuel cell (renewable energy), a Low cost technology with unique performance, instant starts capability, low temperature performance which produce DC voltage. The most promising Fuel cell technology is PEMFC (Proton Exchange Membrane Fuel Cell). The PEMFC stack operates on hydrogen and air. The PEMFC stack is a self-humidified, air-breathing, 60-cell stack. To improve the cooling of the stack, three fans are used. The stack has a maximum operating temperature of 65^0C. In the system we can combine use small capacity battery and fuel cell stack to give backup to different critical loads. Here PEMFC is applied as the main source and battery is connected as the auxiliary source in the UPS, so that the pressure will applied on two sources individually.

1.7 Motivation

Our main goal or target is to save critical loads, to protect them we have to build up a system which can help from being instant shutting down (when grid power is off) by delivering power to the load. So here we do some experiment and simulation of different circuits, how they behave with loads and through this research we can solve some power quality problems that are usually happened in 3rd world countries.

1.8 Organization

In **chapter one,** we discuss about poor power quality and their consequences. Power Quality as a term is defined as the electrical grid's ability to supply a clean and stable power flow to the system. Poor power quality is related to electricity that does not have the necessary characteristics such as voltage and frequency stability that is needed for electrical equipment to function correctly.

In **chapter two,** we studied about the function of different UPS because it can solve such kind of power quality problems; the primary purpose of a UPS is to provide conditioned, continuous power to its load during disturbances like overvoltage, under-voltage, sags or swells. A good UPS has low THD (Total Harmonic Distortion) and clean output voltage for both linear and non linear loads with high efficiency.

To model a UPS, there are some internal electric apparatus, we have analyzed some inverter circuit (bipolar and unipolr PWM inverter) and do simulation with software in **chapter three**.

In **chapter four**, we also examine DC to DC boost converter that is also needed to model a UPS. Here we have analyzed its output whether DC input is boosted up or not. This DC input is supplied from fuel cell stack (renewable energy), the source in parallel with auxiliary source battery.

In last chapter means **chapter five,** we integrate both boost converter and inverter and output is in square wave, for critical loads like computer, digital clock, audio system sine wave is important so we use a low pass filter at the output of inverter to generate sine wave.

Chapter 2
Uninterruptible Power Supply (UPS)

2.1 Introduction

The full form of UPS is uninterruptible power supply also called Continuous power supply. The primary purpose of a UPS is to provide conditioned, continuous power to its load. Another UPS function that is of growing importance in today's market is system integration, or the ability to communicate over a network to facilitate the monitoring and orderly shutdown of loads. It gives backup to the load for several minutes; it depends on the battery capacity. Several ways to integrate the UPS.

2.2 UPS Technologies

Several ways to integrate the UPS,

1. Basic.
2. Enhanced.
3. Network.

Basic: In the UPS two signal are used basically, AC failure and low battery. AC failure arises when supply current does not exist or outages less than 5 second [2].

Enhanced: UPS manufacturer offer RS 232 serial communication that allow to gather real time data to be monitored by the software on the load, user can now monitor the voltage, voltage regulation, ups temperature through the software [2].

Network: The SNMP (Simple Network Management Protocol) capable UPS are internet or network based UPS; it uses the IP address and through the network user can detect smoke, water, voltage, voltage regulation, temperature and so on. It also gives alert via SNMP (it looks like LAN card) [2].

2.3 Different types of UPS:

UPS are of two types:

1. Static UPS.
2. Rotary UPS.

Static UPS are three types:

1. Double conversion online UPS.
2. Line Interactive UPS.
3. Standby power Supply.

2.3.1 Double conversion online UPS:

This is the most common type of UPS above 10kVA. Phase controlled thyristor rectifier is used in this UPS but it causes distortion. So reducing distortion we have to use PWM. Double conversion UPS converts power twice. Firstly utility power (AC) with all its voltage spikes and distortion is converted into DC just like the operation of SMPS (Switched Mode Power Supply). This UPS uses a capacitor to stabilize this DC voltage and store energy from AC input. Secondly DC is converted back into AC, this AC output has different frequency from AC input. When utility power goes out, the UPS provides power from battery to avoid the load instant shut down. The transition between the AC input and battery takes several milliseconds. So in the DC Link (in diagram), there is a capacitor that we discussed earlier. Here capacitor will provide stored energy to the Inverter during this transition so that the output voltage remains unaffected and continuous. In modern designs, an additional battery-charging circuit is almost always included in the topology, so a double-conversion on-line UPS typically has at least three power conversion stages [3].

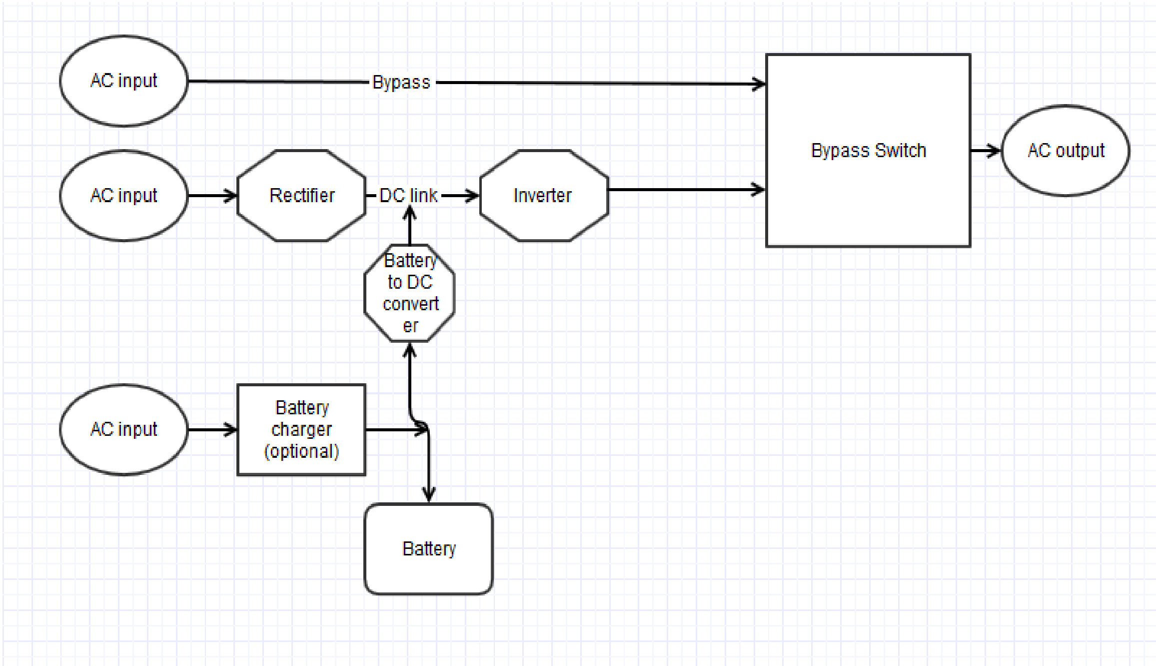


Figure2.1: Double conversion online UPS

Advantages of double-conversion on-line topology:

1. Operates less often from battery when the input voltage is highly distorted or wildly fluctuating.
2. Power factor correction (PFC) provided, regardless of load type.
3. More compact and lightweight, especially at higher power levels.
4. Can regulate output frequency, and even perform frequency “conversion” from 50Hz to 60Hz (and vice versa) [3].

2.3.2 Line Interactive UPS:

In this UPS, inverter interacts with the line so it is called line interactive UPS. This is to ensure that the power runs continuously. It only uses one main power converter. When AC input is available, the power interface block in the figure below filters the AC power suppresses voltage spikes and provides sufficient voltage regulation. Here an inverter is used to charge the battery from AC input. We use tapped transformer to control the phase of the inverter. For example, the inverter block in a 3000-wattline-interactive UPS operates at only 300 watts (1/10th of its capacity) or less while charging its batteries. The small number of components and the cool operation of the main power converter (inverter) both contribute to long life and high reliability. Otherwise for low cost and durability, the line-interactive UPS has been used successfully in millions of IT installations worldwide [3].

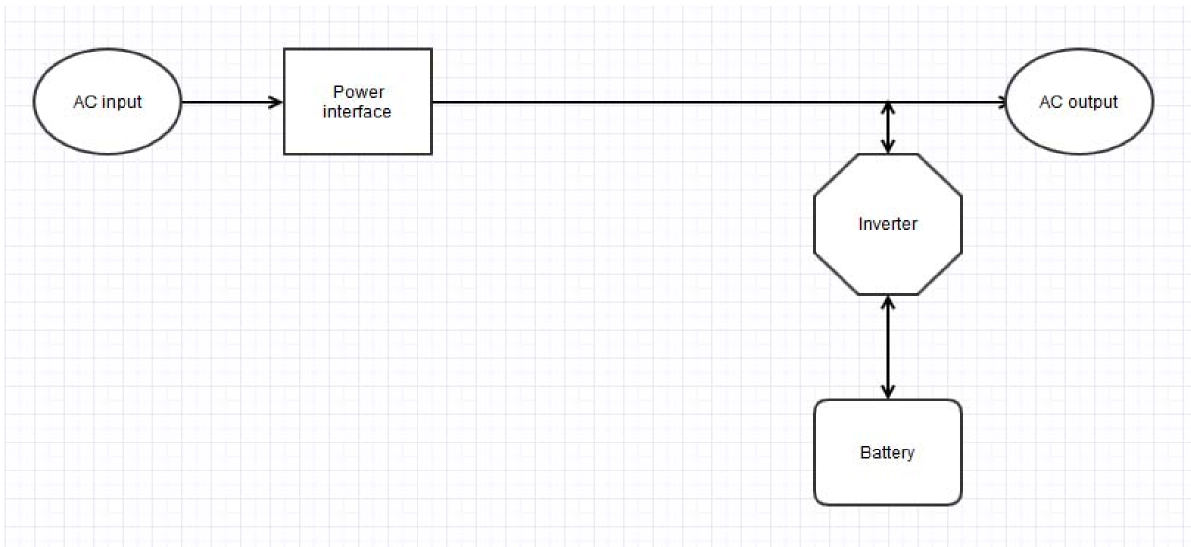


Figure 2.2 Line interactive UPS

Advantages of line-interactive topology:

1. Lower electricity consumption (less costly to operate) – More efficient because less power conversion is performed when acceptable AC input is present.
2. Less heat load on the facility – Less heat is produced by the UPS.
3. High-quality line-interactive units have powerful built-in surge and noise suppression to keep their output within acceptable levels so that the Load's reliability is not affected [3].

2.3.3 Standby power Supply

These types of UPS do not provide continuous power to the load, so they are not proper UPS. The Standby UPS are under 10kVA. The standby DC to DC converter from the battery is switched on when an AC power failure is detected. The battery charger is also small. Here the output wave is square wave or stepped square wave, it is low cost and low VR (Voltage Regulation) [2].

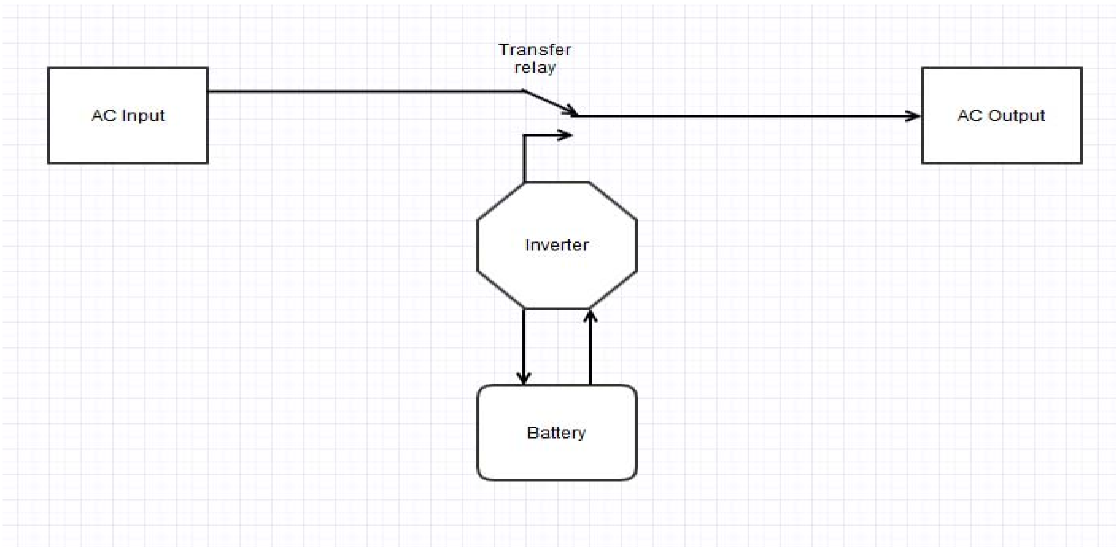


Figure 2.3: Standby power Supply

2.3.4 Rotary UPS

It is a motor and generator combination, here they used DC motor coupled to AC generator and provide uninterruptable power to the load. They use common shaft between the motor and generator. Rotary UPS are available from 35 KVA to 1000KVA, in today's time manufacturer use AC motor because it need not maintain the brush. In rotary UPS motor and generator at stator side and DC field at rotor side, this UPS cannot start from inverter, so it uses secondary motor to start the rotation [2].

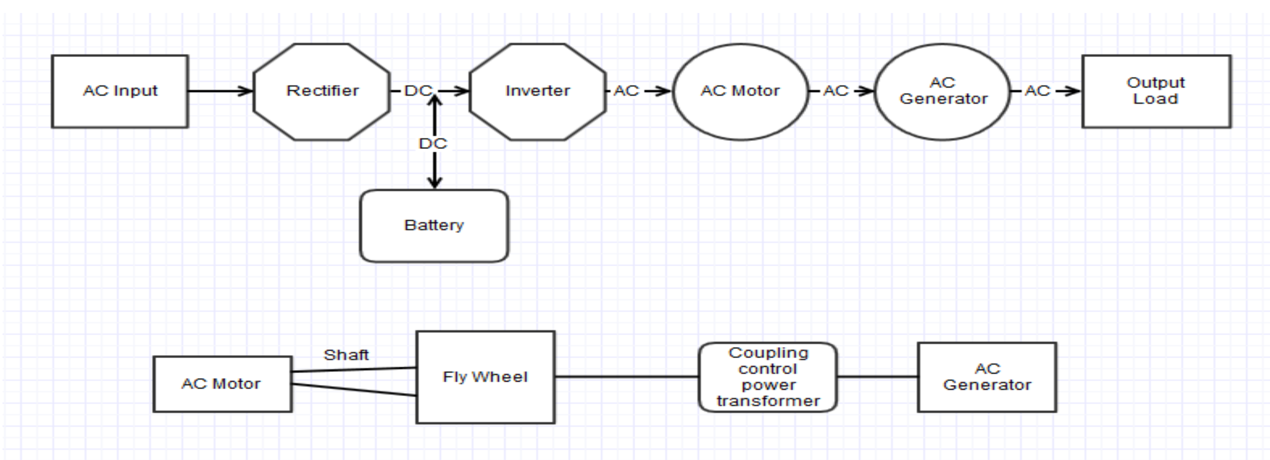


Figure 2.4: Rotary UPS

Advantages of Rotary UPS:

Due to its low impedance, the rotary UPS' overload capability is approximately 10 times its continuous rating. Therefore, a rotary system will have superior fault clearing capability. It can also supply currents for high inrush loads, such as transformers. Another advantage is the rotary unit offers isolation from harmonic distortion generated by nonlinear loads connected to the normal utility service. It's also able to operate reliably at higher ambient temperatures [4].

2.4 A survey on UPS existing in market

UPS name(offline)	**Rating (VA)**	**Display in front side of UPS (Diff. Color LED light)**	**input/output voltage**
Micro	1000 VA	AC Normal Inverter Charging	285/220V
Mercury	650 VA	AC Normal Charging	285/220V
Prolink	1200VA	AC Normal Charging	140-285/220V
Apollo	1200 VA	AC Normal Inverter Charging	240/120V

2.5 Application UPS

Multiple redundancies: Many computer servers offer the option of redundant power supplies, so that in the event of one power supply failing, one or more other power supplies are able to power the load. This is a critical point – each power supply must be able to power the entire server by itself. Redundancy is further enhanced by plugging each power supply into a different circuit [5].

Outdoor use / Military UPS: When a UPS system is placed outdoors, it should have some specific features that guarantee that it can tolerate weather with a 'minimal to none' effect on performance. Factors such as temperature, humidity, rain, and snow among others should be considered by the manufacturer when designing an outdoor UPS system. Operating temperature ranges for outdoor UPS systems could be around −40 °C to +55 °C.

Outdoor UPS systems can be pole, ground (pedestal), or host mounted. Outdoor environment could mean extreme cold, in which case the outdoor UPS system should include a battery heater mat, or extreme heat, in which case the outdoor UPS system should include a fan system or an air conditioning system. Military UPS designs are further enhanced to withstand the environmental pressures and stresses of continuous use or quick deployment in different environments / climates [5].

Internal systems: UPS systems can be designed to be placed inside a computer chassis. There are two types of internal UPS. The first type is a miniaturized regular UPS that is made small enough to fit into a 5.25-inch CD-ROM slot bay of a regular computer chassis. The other type are re-engineered switching power supplies that utilize dual power sources of AC and/or DC as power inputs and have an AC/DC built hi-switching management control units [5].

2.6 Cost and environmental effect by using UPS:

UPS uses technology and operational efficiencies to reduce fuel consumption and emissions.

1. UPS is committed to a sustainable future, and the company's alternative fuel vehicles play a large role in that commitment. UPS operates a fleet of more than 2,000 alternative fuel vehicles that make deliveries to homes and businesses every day [6].
2. UPS operates more than 709 propane-powered vehicles in Canada and Mexico [6].
3. Because of significant improvements in battery engineering during recent years, electric vehicle technology is now viable for vehicles that operate short distances per day and allow for periods of recharging to the system. In October 2004, UPS deployed an electric vehicle to deliver packages in Manhattan. A second electric vehicle was introduced in 2005. This technology, besides producing zero emissions, may allow us to greatly reduce maintenance cost and environmental impact [6].

Chapter 3

Model of UPS

INVERTER

3.1 Function of inverter circuit:

Inverters take the DC power supplied by a storage battery bank and electronically convert it to AC power. The inverter allows AC electrical appliances to be run from the storage battery bank. When the battery bank becomes discharged, the inverter can automatically start a generator to power the system while the batteries recharge. Utility power will be used when alternative power sources are insufficient. Inverters also include overvoltage and under voltage protection, protecting sensitive equipment from dangerous power surges as well.

3.2 Advantage of using MOSFET as switch in inverter circuit:

High input impedance - voltage controlled device - easy to drive.

Majority carrier device - fast switching speed.

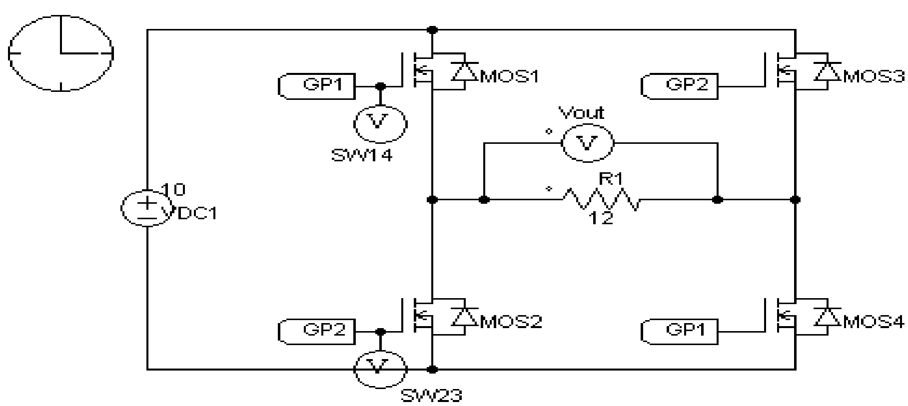
Wide SOA (safe operating area). It has a wider SOA than the BJT.

Forward voltage drop with positive temperature coefficient - easy to use in parallel.

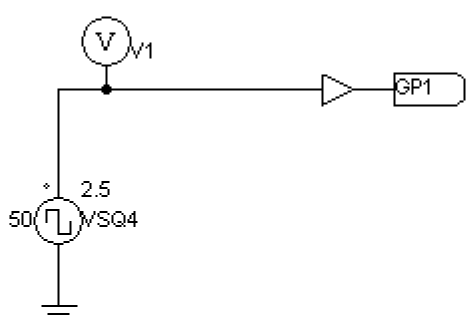
So the thing is telling that it is a voltage controlled device [7].

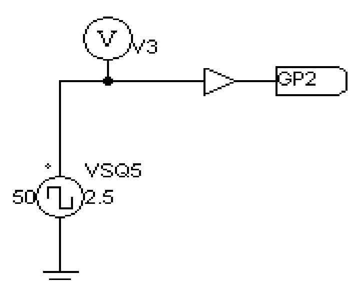
3.3 Square wave Inverter:

The simplest switching scheme for the full-bridge converter produces a square wave output voltage. The switches connect the load to +Vdc when S1 and S4 are closed or to -Vdc when S2 and S3 are closed. The periodic switching of the load voltage between +Vdc and -Vdc produces a square wave voltage across the load [8] and figure 3.1 shows square wave full bridge inverter and their switching signals. In this inverter circuit we use four switches (S1, S2, S3, and S4) and in this switches we give two different types of gate pulse. For a series load and a square wave output voltage we assume that S1 and S4 close at t = 0 and in S1 and S4 we give GP1 then the voltage across the load is +Vdc. At t = T/2, S1 and S4 open, and S2 and S3 close, so the voltage across the load becomes -Vdc and in S2 and S3 we give GP2.



(a)





(b) (c)

Figure 3.1: Square wave inverter (a), gate pulse for sw14 (b), gate pulse for sw23(c)

3.3.1 Signals for Switches 1&4:

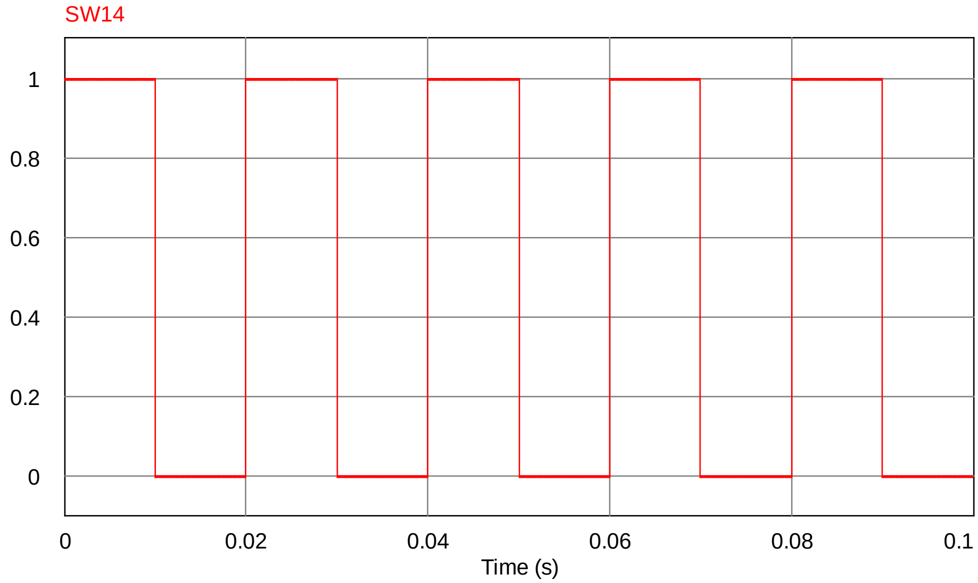


Figure 3.1.1: Switching signals for switch 1 and 4

3.3.2 Signals for Switches 2&3:

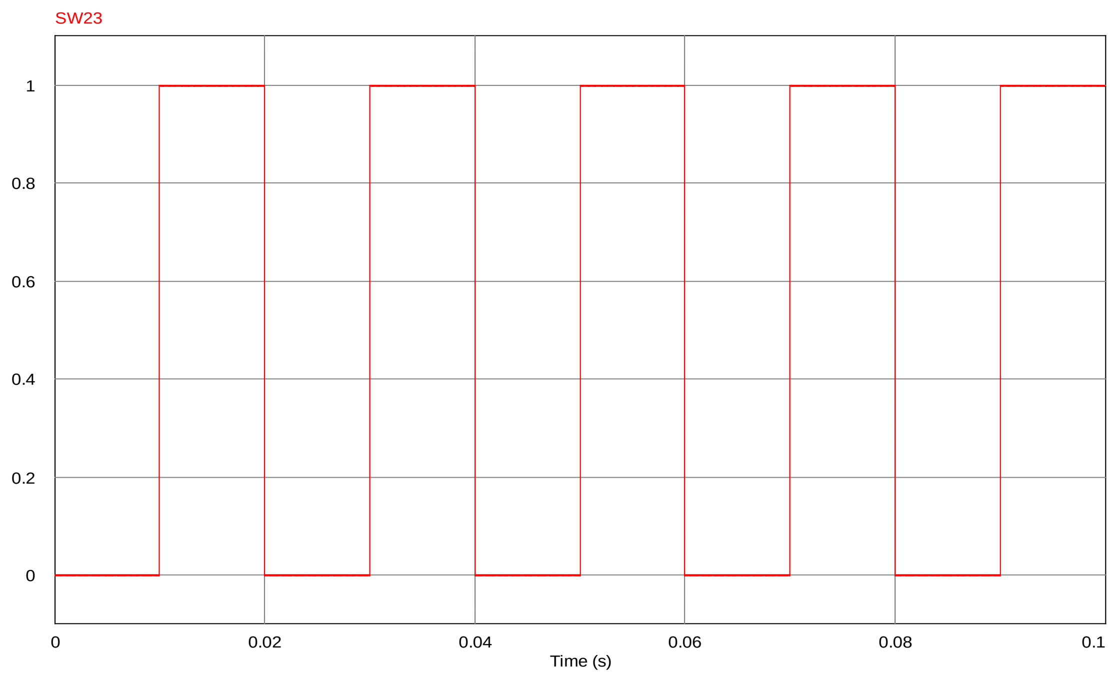


Figure 3.1.2: Switching signals for switch 2 and 3

3.3.3 Output waveform:

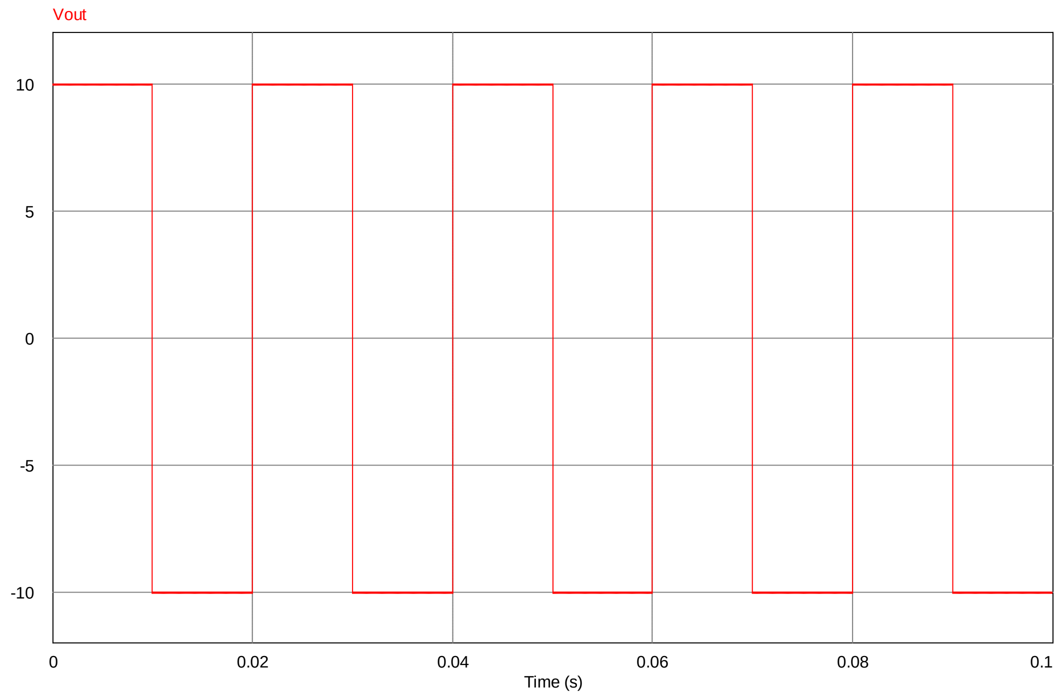


Figure 3.1.3: Output waveform of square wave inverter

3.3.4 FFT analysis:

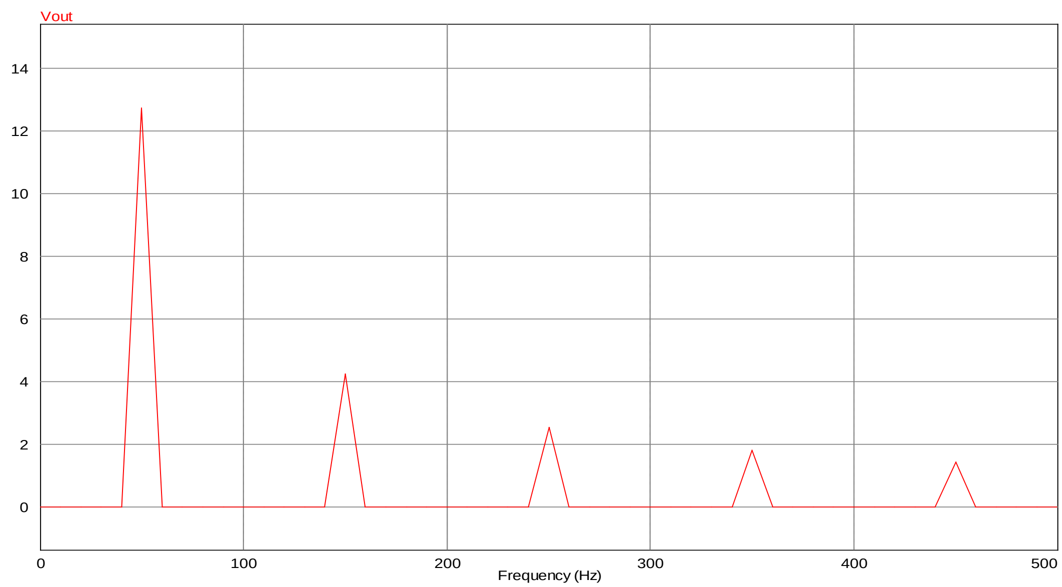


Figure 3.1.4: Fourier transform

3.3.5 Demerits of Square wave inverter:

1. Output depends on input; if input increases output will also increase and vice versa. Any change of input cannot produce the required output by using square inverter.
2. If we observe the FFT, it shows that there is a fundamental frequency and harmonics, first harmonic is 3 times of the fundamental frequency at 150Hz and others are 5, 7 and 9 times of fundamental frequency (at 250Hz, 350Hz, 450Hz).

3.4 PWM inverter:

PWM inverters function by comparing sinusoidal control signal at the desired output frequency with a triangular carrier signal at switching the frequency which is typically in the kHz range. It means the output wave form of PWM inverter appears more sinusoidal than a square wave inverter. Moreover higher frequency harmonics are easier to filter than harmonics near the fundamental frequency.

In PWM, the amplitude of the output voltage can be controlled with the modulating waveforms. By reducing filter requirements to decrease harmonics and the control of the output voltage amplitude are two distinct advantage of PWM [8].

Frequency modulation ratio mf: The Fourier series of the PWM output voltage has a fundamental frequency which is the same as the reference signal. Harmonic frequencies exist at and around multiples of the switching frequency. The magnitudes of some harmonics are quite large, sometimes larger than the fundamental. However, because these harmonics are located at high frequencies, a simple low-pass filter can be quite effective in removing them.

$$mf = f\,(carrier)/f(reference) = f(tri)/f(sine)$$

Increasing the carrier frequency (increasing mf) increases the frequencies at which the harmonics occur. A disadvantage of high switching frequencies is higher losses in the switches used to implement the inverter [8].

Amplitude modulation ratio ma: The amplitude modulation ratio ma is defined as the ratio of the amplitudes of the reference and carrier signals [8].

$$ma = Vm\,(reference)/Vm\,(carrier) = Vm(sine)/Vm\,(tri) \quad [when,\ ma \le 1]$$

3.4.1 Functions of PWM:

PWM switching system is two types,

1. Bipolar switching
2. Unipolar switching

Bipolar switching: When the instantaneous value of the sine reference is larger than the triangular carrier, the output is at +*V*dc, and when the reference is less than the carrier, the output is at –*V*dc. [8]

$$Vout = + Vdc \quad \text{when } Vsine > Vtri$$

$$Vout = -Vdc \quad \text{when } Vsine < Vtri$$

Unipolar switching: In a unipolar switching scheme for pulse-width modulation, the output is switched either from high to zero or from low to zero, rather than between high and low as in bipolar switching [8].

3.4.2 Bipolar PWM inverter

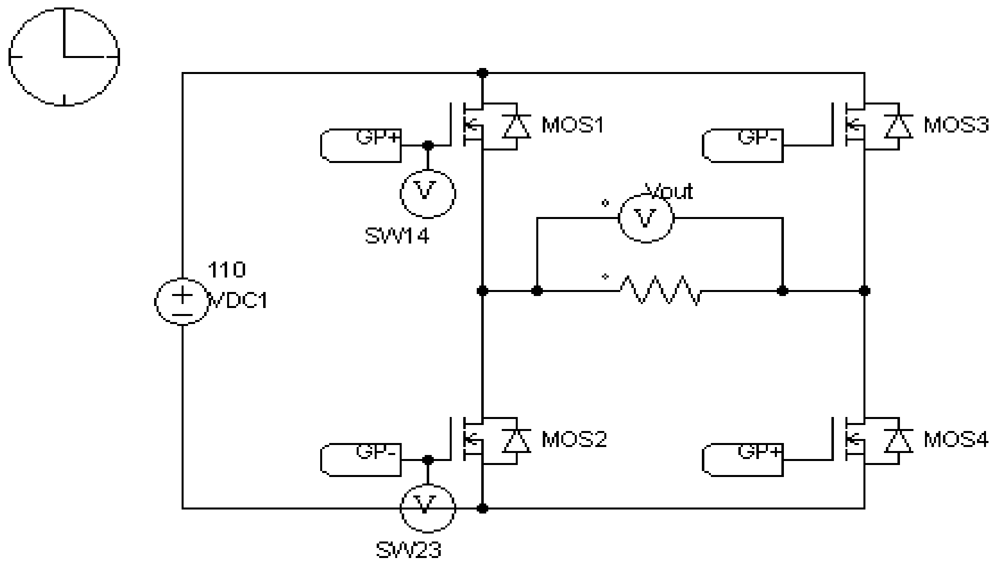
Condition for switching**:**

The switching scheme that will implement bipolar switching using the full-bridge inverter of Figure below is determined by comparing the instantaneous reference and carrier signals [8].

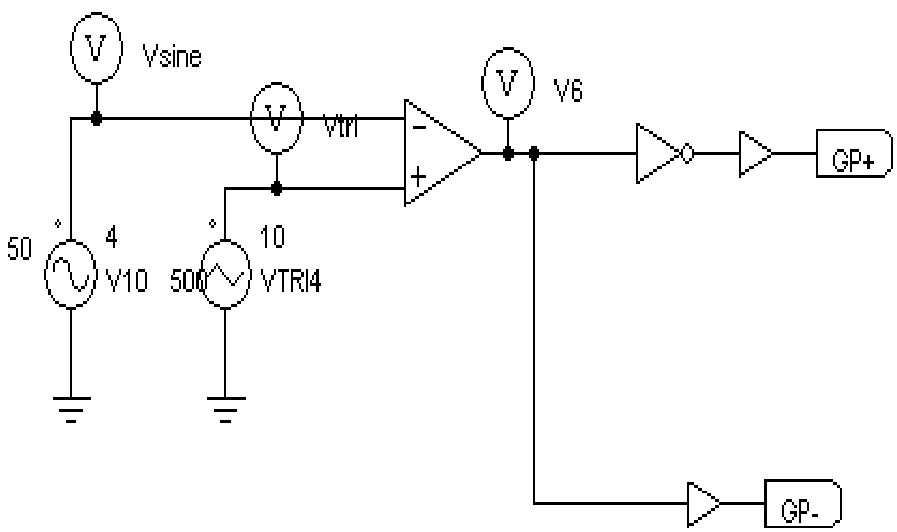
S1 and S2 are on when Vsine>Vtri (Vout = +Vdc)

S3 and S4 are on when Vsine<Vtri (Vout = -Vdc)

Here figure 3.6 shows bipolar PWM full wave bridge inverter and their switching signals. When the instantaneous value of the sine reference is larger than the triangular carrier, the output is at +Vdc, and when the reference is less than the carrier, the output is at –Vdc. In this inverter circuit we use four switches (S1, S2, S3, and S4) and in this switches we give two different types of gate pulse. For a series load and a square wave output voltage we assume that S1 and S4 close at t = 0 and in S1 and S4 we give GP+ then the voltage across the load is +Vdc. At t = T/2, S1 and S4 open, and S2 and S3 close, so the voltage across the load becomes -Vdc and in S2 and S3 we give GP -.



(a)



(b)

Figure 3.6: Bipolar PWM inverter circuit (a), gate pulse (GP+) for sw14 (b), gate pulse(GP-) for sw23(b)

3.4.3 Combine waveform for Vsine and Vtri:

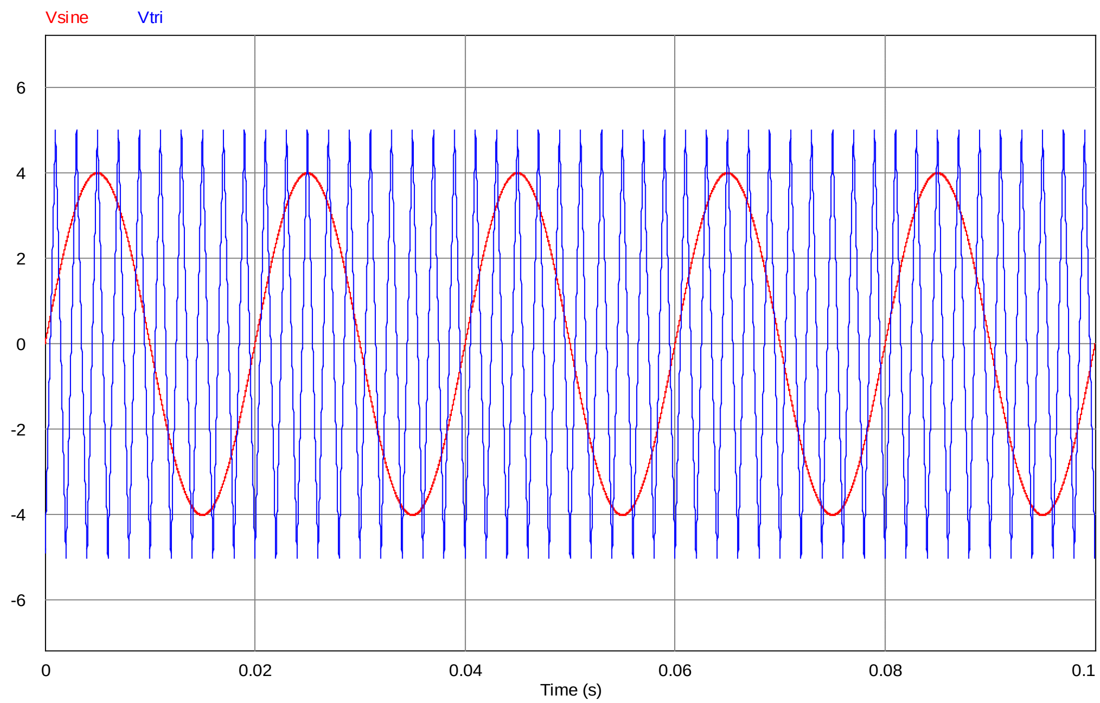


Figure 3.6.1: Waveform for Vsine and Vtri

3.4.4 Signals for Switch 1 & 4:

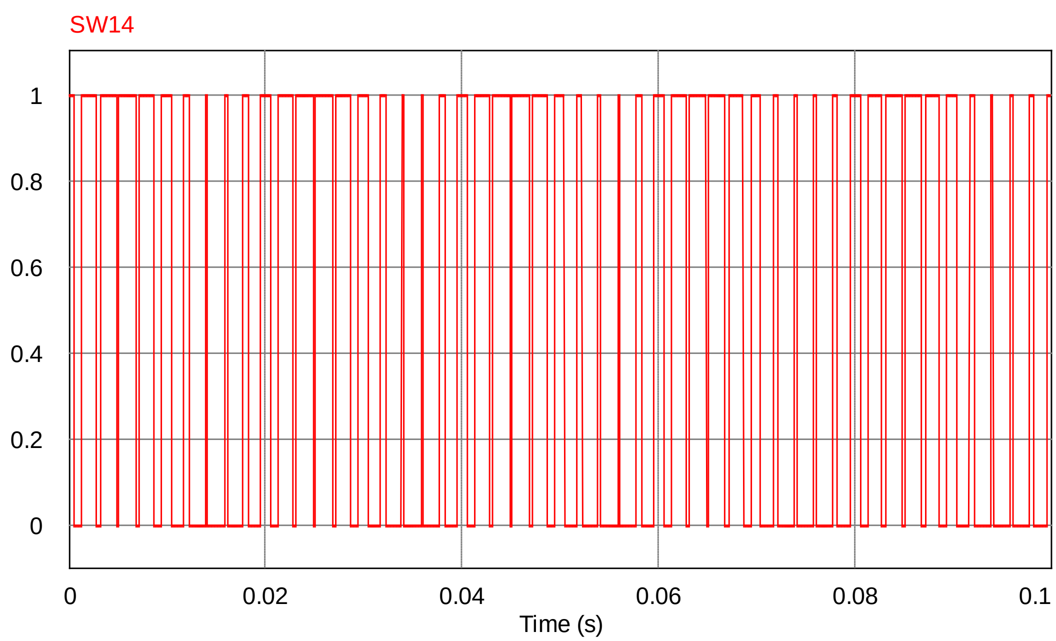


Figure 3.6.2: Switching signals for Switch 1 and 4

3.4.5 Signals for Switch 2 & 3:

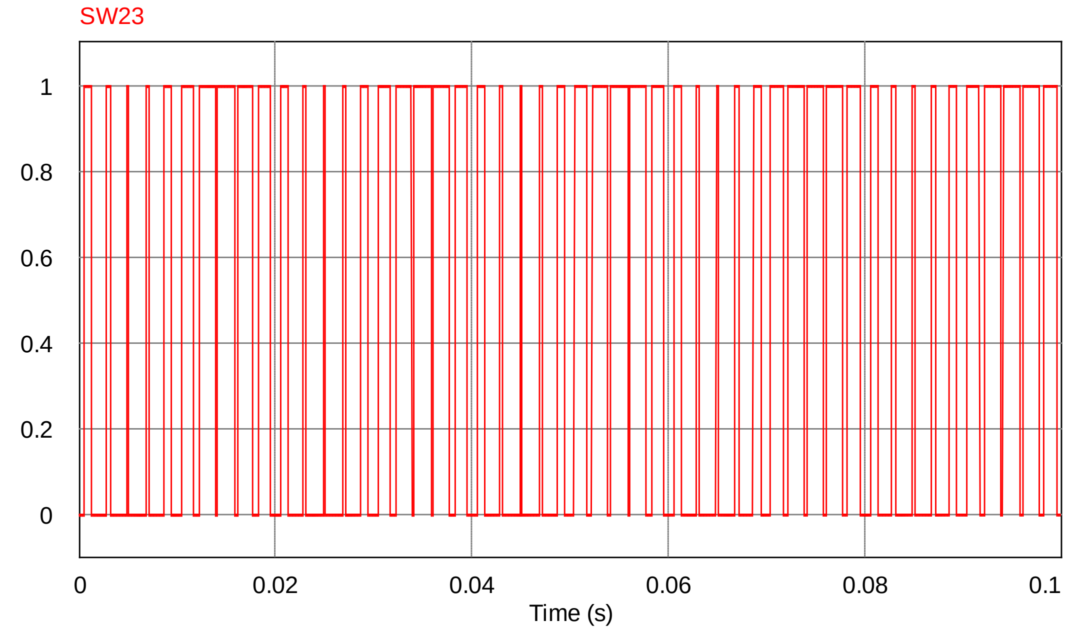


Figure 3.6.3: Switching signals for Switch 2 and 3

3.4.6 Output waveform for PWM inverter (bipolar):

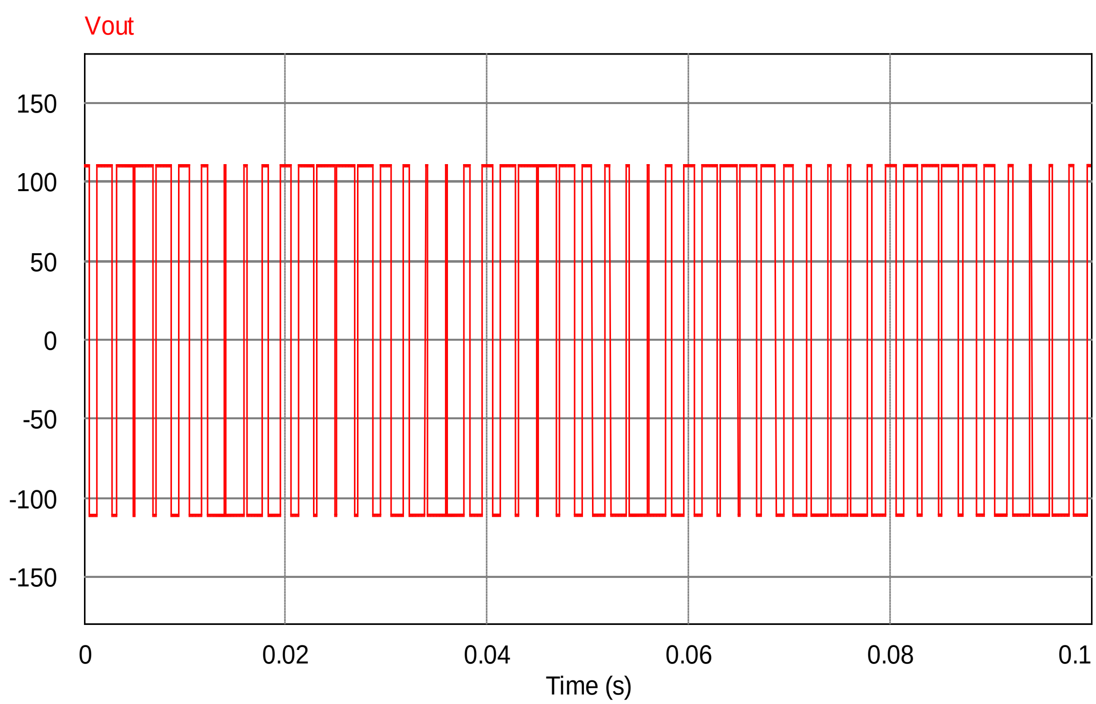


Figure 3.6.4: A typical Output waveform for bipolar PWM inverter circuit

3.4.7 FFT analysis:

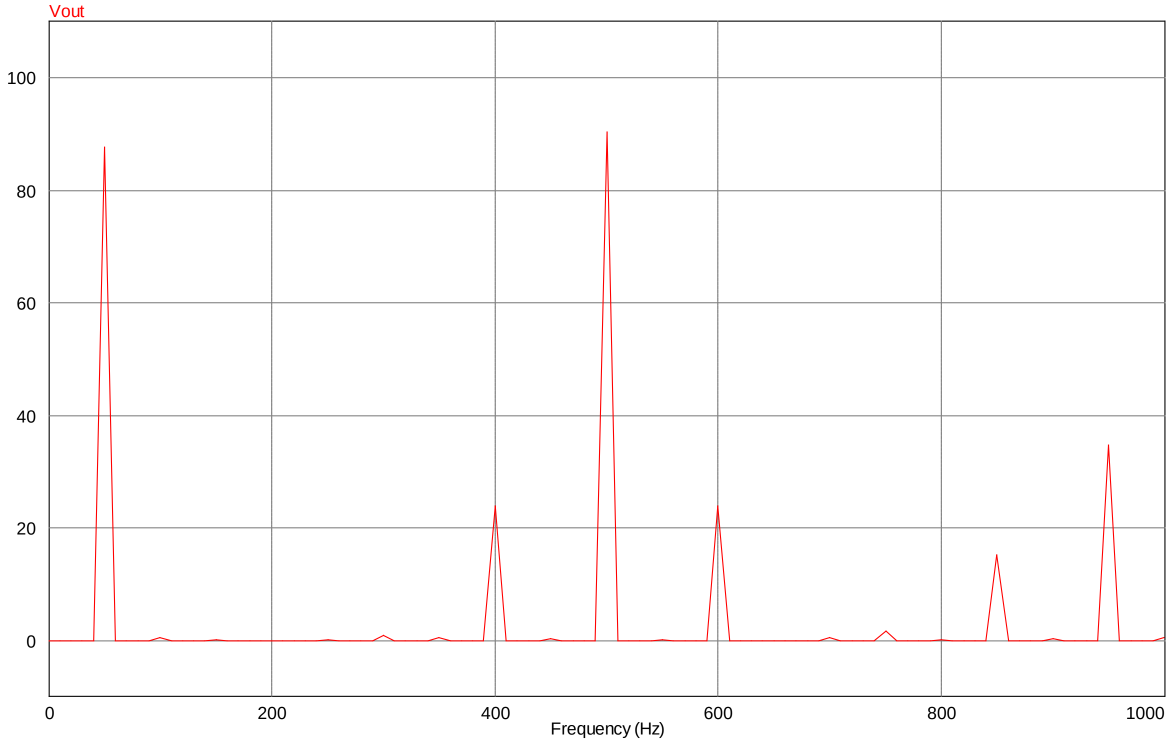


Figure 3.6.5: Fourier Transform

After analyzing the FFT we can see that at fundamental frequency there is a spike but after fundamental frequency at 3rd, 5th, 7th there is harmonics, so we can reduce them by using filter after inverter output.

3.4.8 Amplitude modulation ratio (ma) by varying Vsine amplitude (bipolar):

m_a(amplitude modulation ratio)	V_f (voltage at fundamental frequency)	V(rms)
0.1	10.90	7.70
0.2	20.80	14.70
0.3	31.64	22.37
0.4	42.78	30.25
0.5	54.05	38.21
0.6	65.06	46
0.7	75.27	53.22
0.8	86.10	60.88
0.9	97.54	68.97

3.4.9 Unipolar PWM inverter

Condition for switching: One unipolar switching scheme has switch controls in figure below [8].

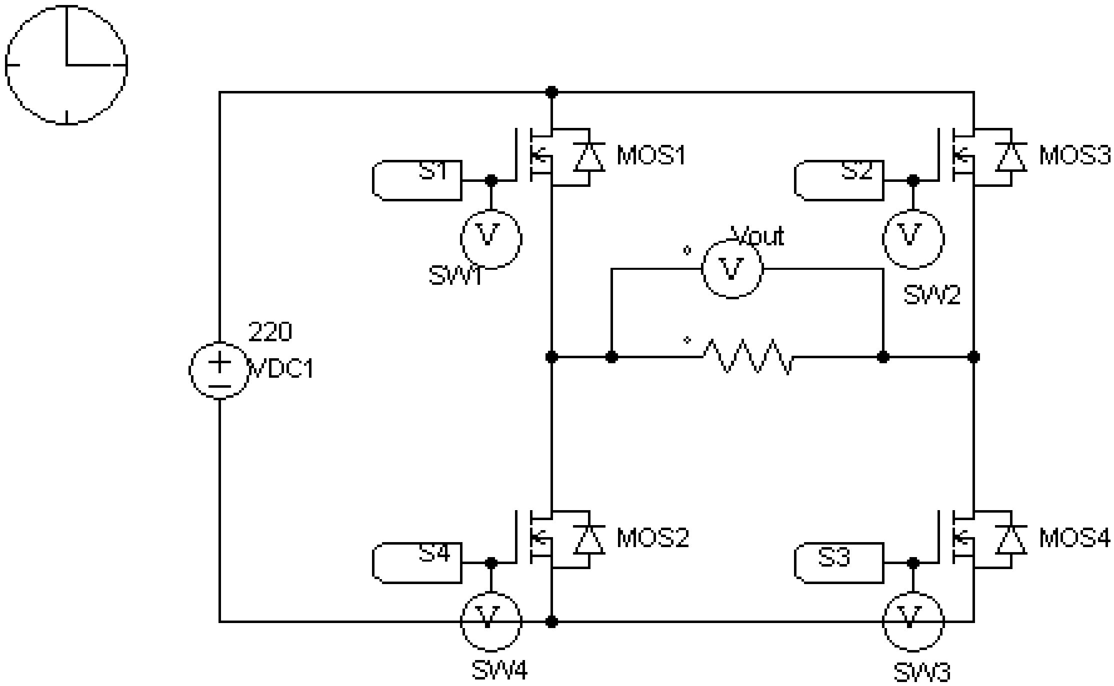
S1 is on when Vsine>Vtri

S2 is on when -Vsine<Vtri

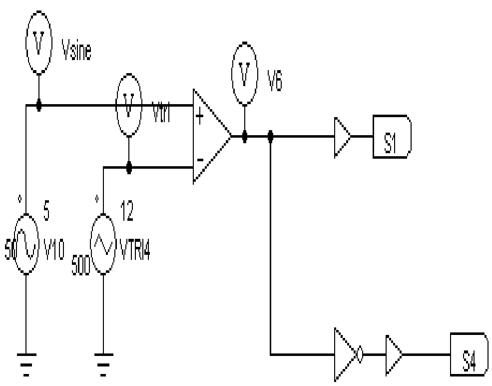
S3 is on when -Vsine>Vtri

S4 is on when Vsine<Vtri

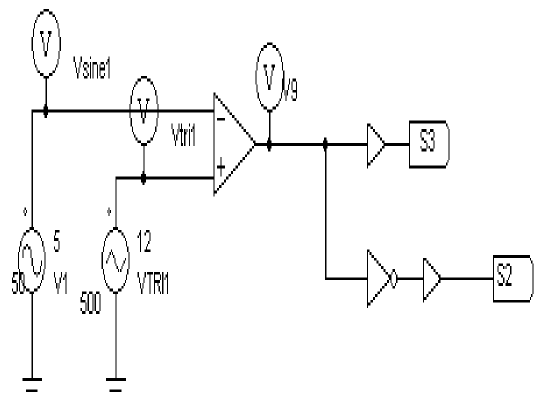
Here figure 3.12 shows unipolar PWM full wave bridge inverter and their switching signals. Note that switch pairs (S1, S4) and (S2, S3) are complementary when one switch in a pair is closed, the other is open. The voltages at S4 and S3 are alternate between +Vdc and zero. The output voltage or voltage across the load, Vo is equal to voltage difference between S4 and S3.



(a)



(b)



(c)

Figure 3.12: Unipolar PWM inverter (a), gate pulse for sw14 (b), gate pulse for sw23 (b)

3.5.0 Combine waveform for Vsine and Vtri:

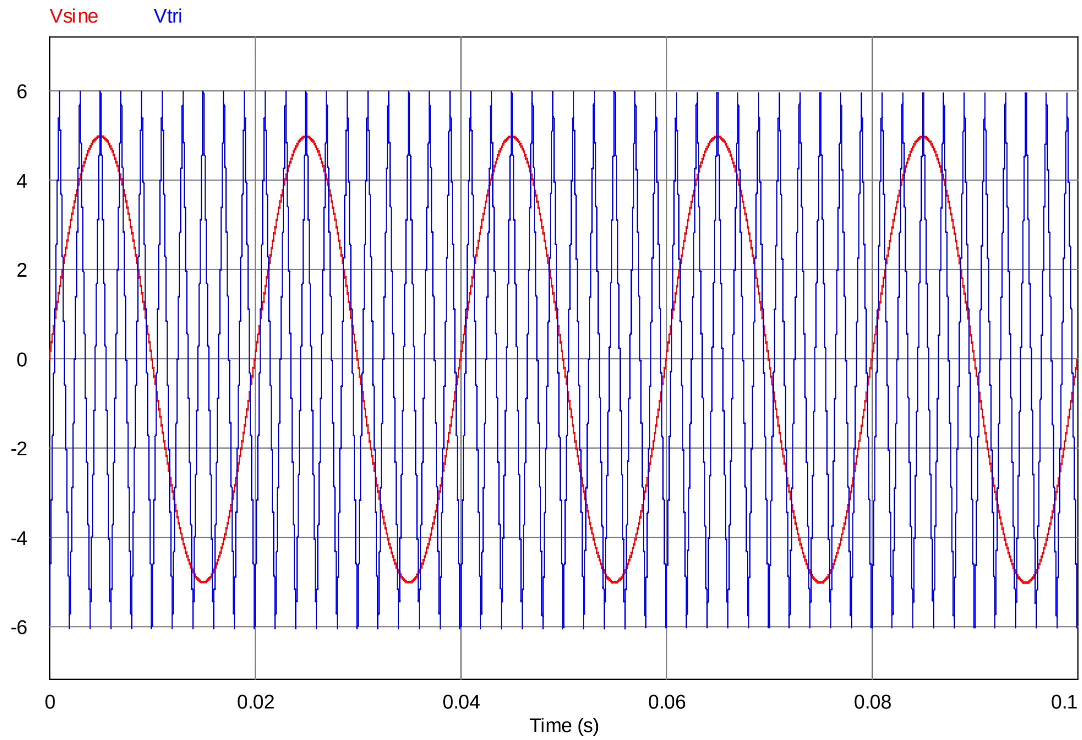


Figure 3.12.1: Waveform for Vsine and Vtri

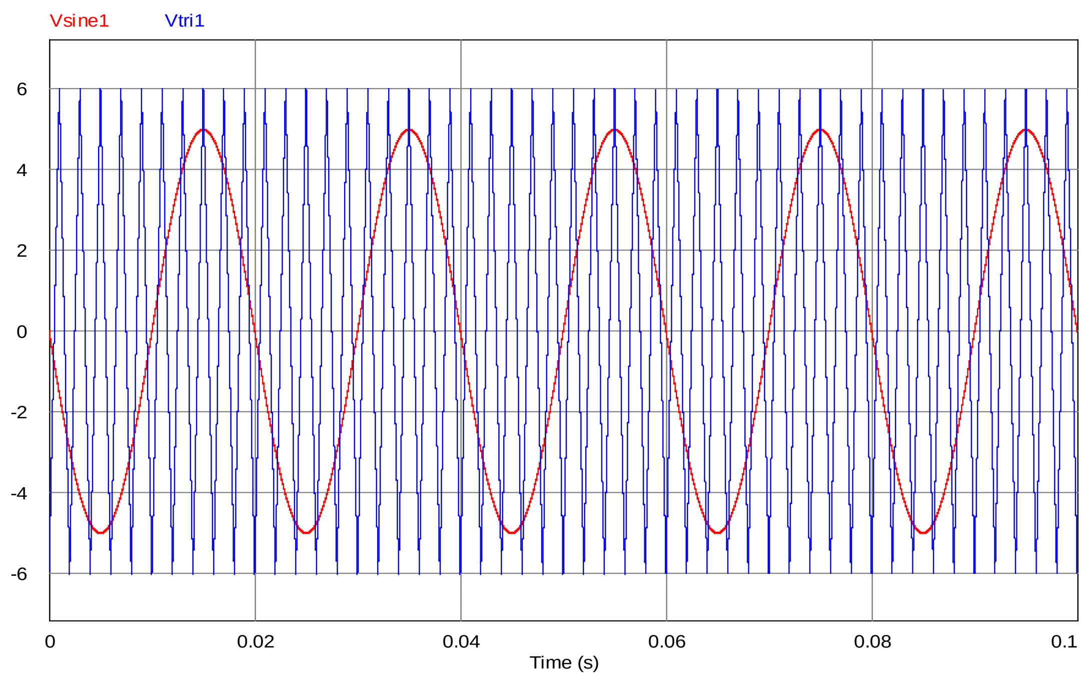


Figure 3.12.2: Waveform for Vsine1 and Vtri1

3.5.1 Signals for all four Switches:

Figure 3.12.3: Switching signals for sw (1,2,3,4)

3.5.2 Output waveform for PWM inverter (Unipolar):

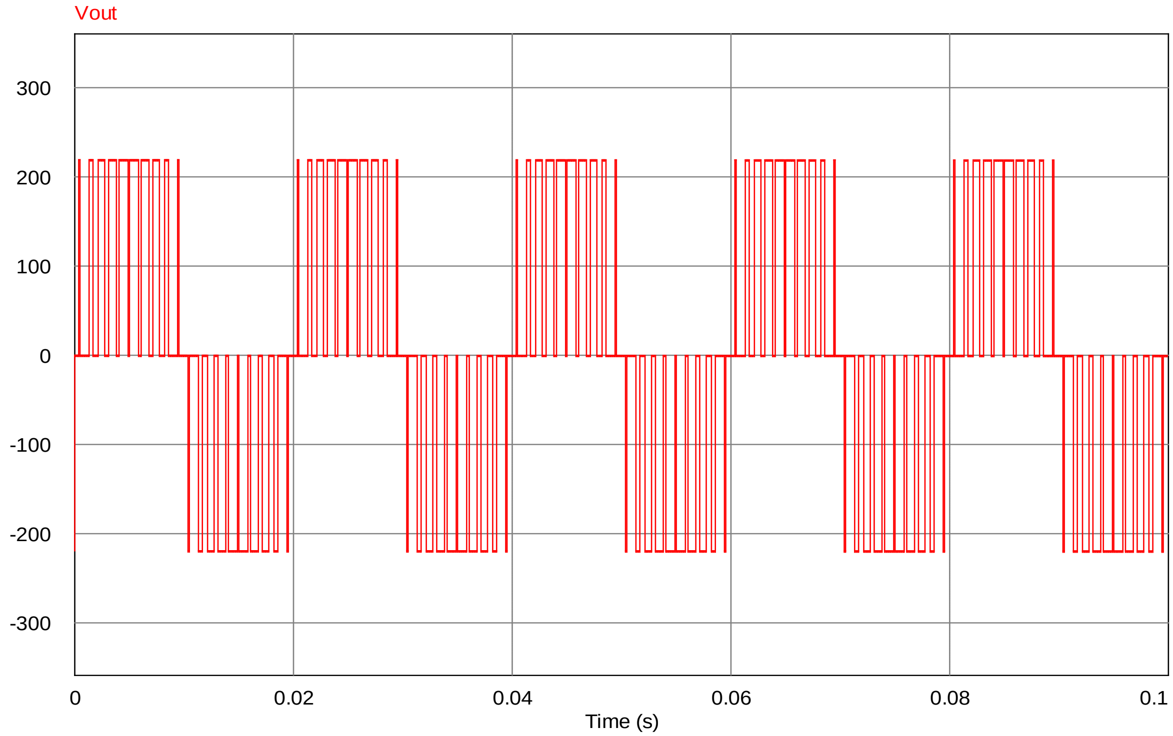


Figure 3.12.4: A typical Output waveform for PWM inverter circuit

3.5.3 FFT analysis:

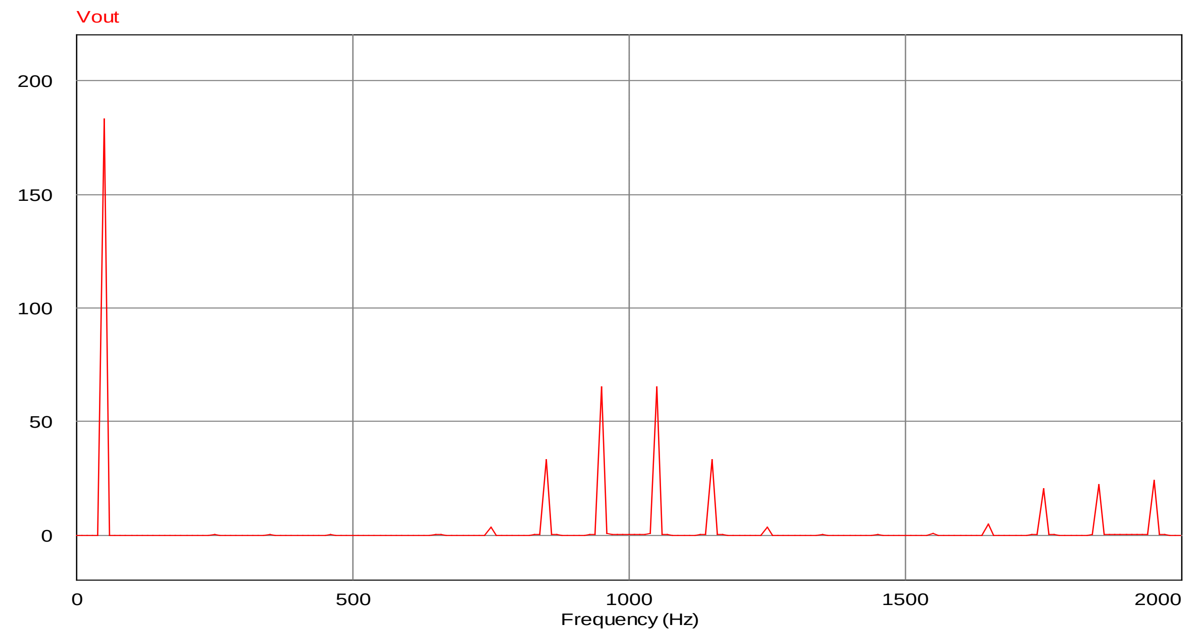


Figure 3.12.5: Fourier Transform

3.5.4 Amplitude modulation ratio (ma) by varying Vsine amplitude (Unipolar):

m_a(amplitude modulation ratio)	V_f (voltage at fundamental frequency)	V(rms)
0.1	21.36	15.10
0.2	42.61	30.12
0.3	64.57	45.65
0.4	86.07	60.86
0.5	110	77.78
0.6	131.2	92.77
0.7	152.7	107.97
0.8	175.2	123.88
0.9	194.92	137.83

Chapter 4

Boost Converter

4.1 Introduction:

A boost converter is a DC to DC converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing at least two semiconductor a Diode and a MOSFET and at least one energy storage element and a capacitor, inductor. Filters made of capacitor are normally added to the output of the converter to reduce output voltage ripple. A boost converter is used as the voltage increase mechanism in the circuit mainly steps up converter [9].

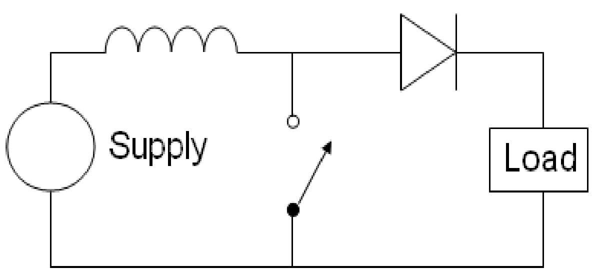


Figure 4.1: Basic schematic of boost converter

4.2 Voltage relationship of boost converter:

This analysis for two positions, switch closed and switch open [8]

SWITCH CLOSED,

$$V(L) = V(s) = L*[di(L)/dt] \quad \text{or} \quad di(L)/dt = V(s)/L$$

The rate of change of current is constant, so the current increases linearly. The change in inductor current is,

$$\Delta i(L)/ \Delta t = \Delta i(L)/DT = V(s)/L$$

So for switch closed,

$$[\Delta i(L)]closed = [V(s)*D*T]/L$$

SWITCH OPEN,

When switch is open the inductor current can not change instantly so the diode become forward biased.

$$V(L) = V(s) – Vout = L*[di(L)/dt]$$

$$[di(L)/dt] = [V(s) – Vout]/L$$

The rate of change of inductor current is constant, so the current must change linearly. The change in inductor current is,

$$\Delta i(L)/ \Delta t = \Delta i(L)/(1-D)*T = [V(s) – Vout]/L$$

So for switch open,

$$[\Delta i(L)]open = [(V(s) – Vout)*(1-D)*T]/L$$

For steady state operation the net change in inductor current is zero,

$$[\Delta i(L)]closed + [\Delta i(L)]open = 0$$

$$V(s)(D+1-D) – Vout(1-D) = 0 ,$$

$$Vout = V(s)/(1-D)$$

4.3 Calculating different parameters:

Here we need the value of inductor and capacitor [8]

We know, L(min) = $\frac{[D(1-D)\hat{}2\times R]}{(2\times f)}$

We have to take value of L more than L(min), L > L(min)

Equation for capacitor value (less than 1%) =

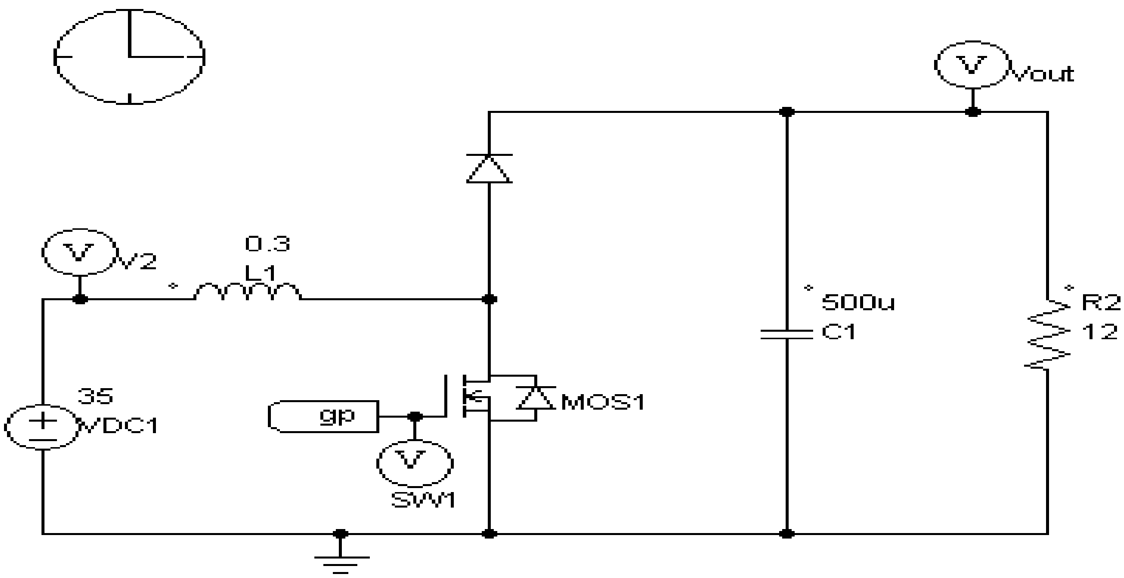
$$C = \frac{D}{R\left(\frac{\Delta V_o}{V_o}\right) f}$$

D = duty ratio, R = resistance, f = frequency,

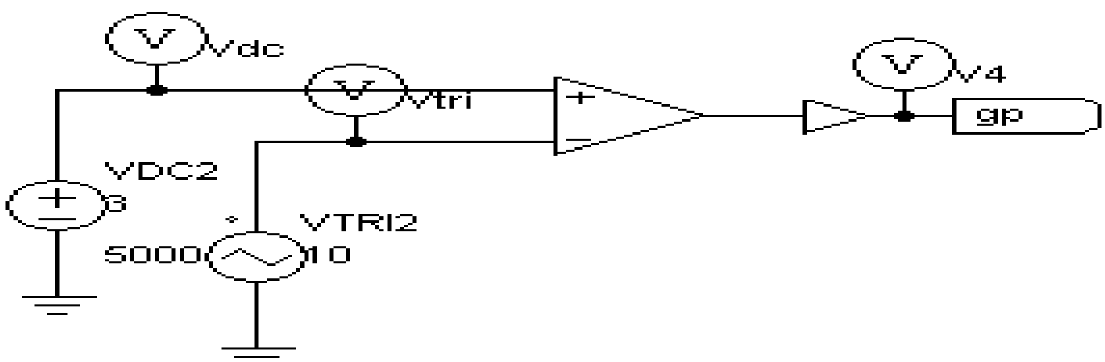
Current flowing through the inductor is, I(L) = $\frac{V(S)}{[(1-D)\hat{}2]\times R}$

4.3.1 Circuit diagram of Boost converter:

In the boost converter circuit, we are giving 35V DC voltage from fuel cell and we give dc and triangular wave to the comparator at a frequency of 5000Hz. Then it passes through an on-off switch and connected to the gate pulse shown in Figure 4.2(a). Then the boost converter boosts the dc voltage. In Figure 4.2.1 we can see the combination of Vdc and Vtri. In the same way we get output waveform shown in Figure 4.2.3, in this waveform we can understand that DC voltage has boosted up from 35V to 50V (approximately), we also analyze Fourier Transform in Figure 4.2.4



(a)



(b)

Figure 4.2: Boost converter circuit (a), gate pulse for sw1 (b)

4.3.2 Combine waveform for Vdc and Vtri:

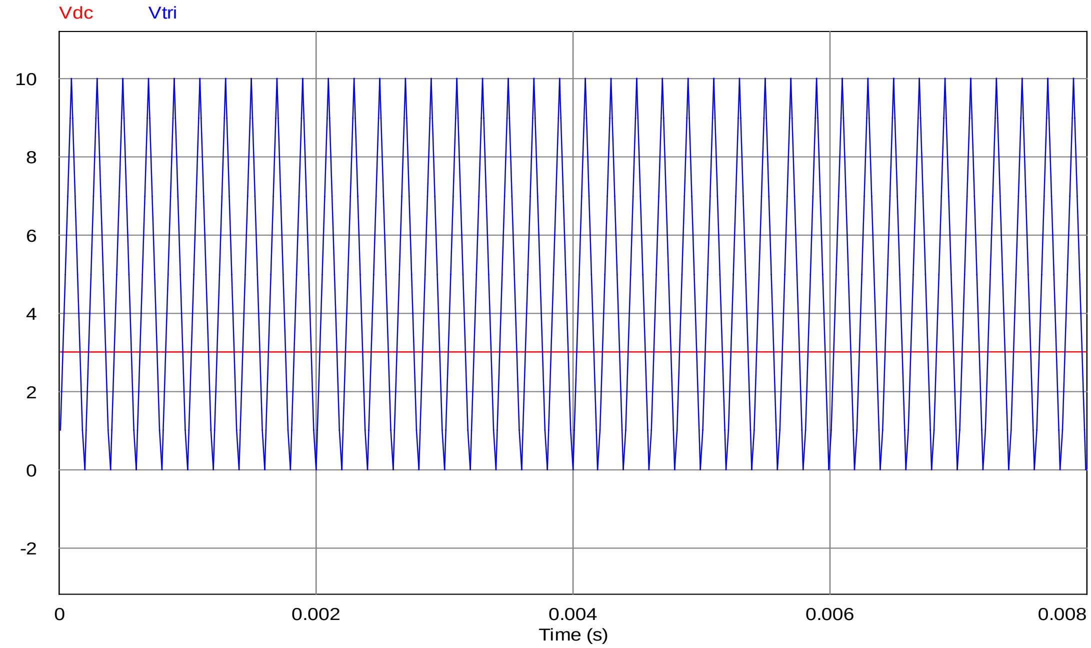


Figure 4.2.1: waveform for Vdc and Vtri

4.3.3 Signal for switch 1:

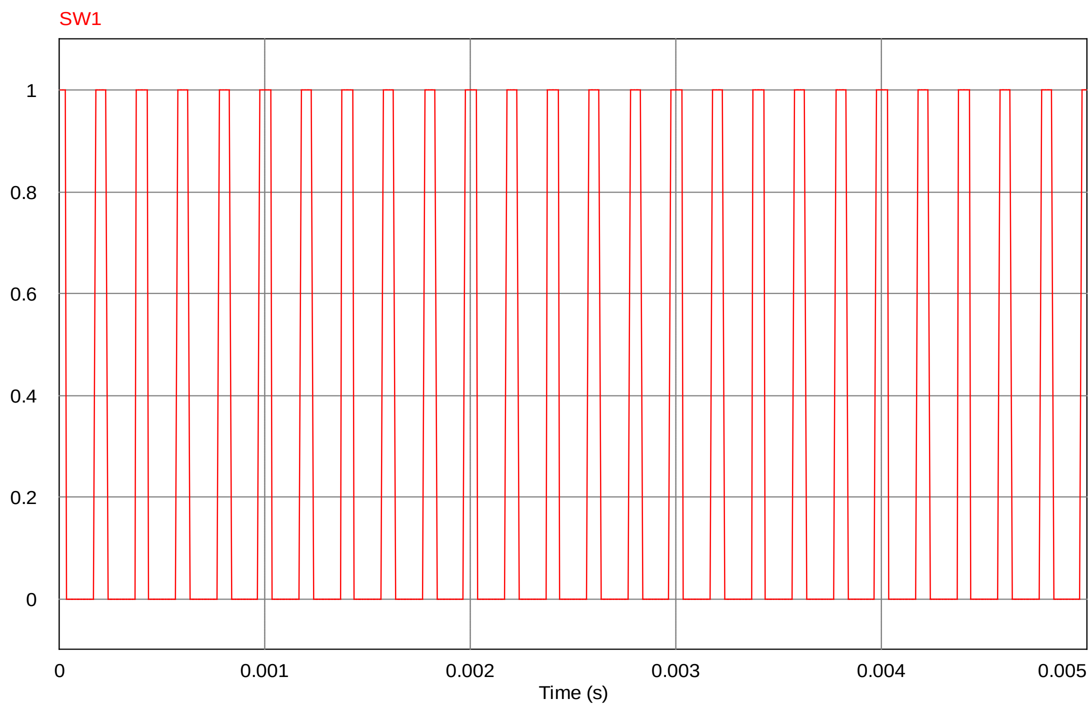


Figure 4.2.2: Switching signal for sw1

4.3.4 Output waveform:

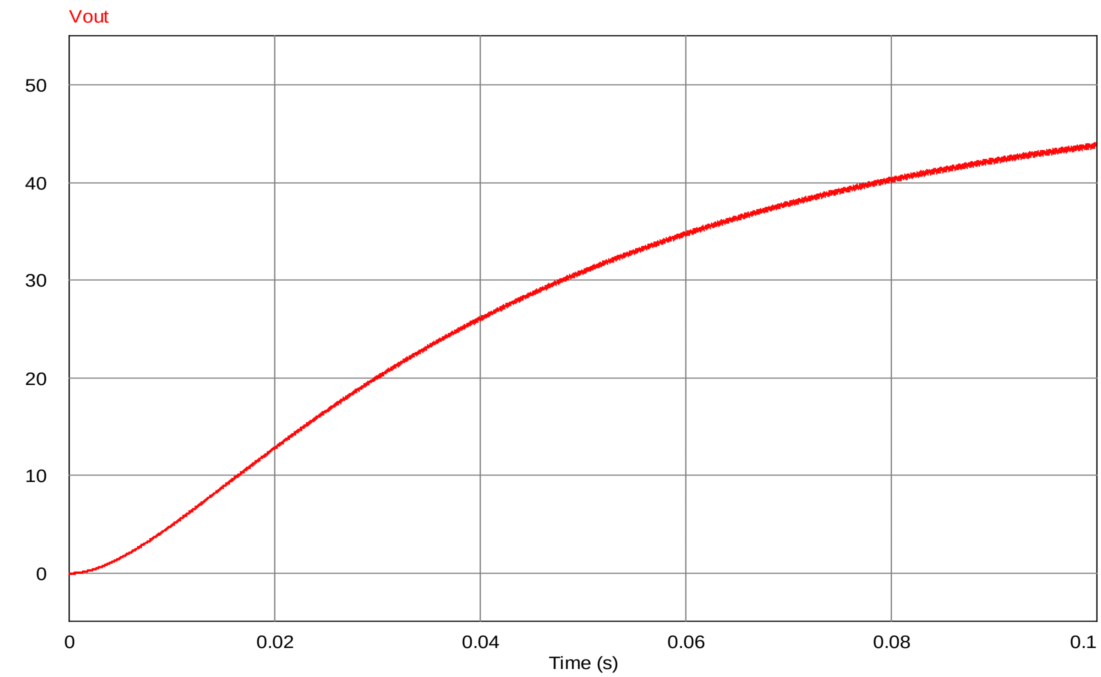


Figure 4.2.3: Output waveform of boost converter

4.3.5 FFT analysis:

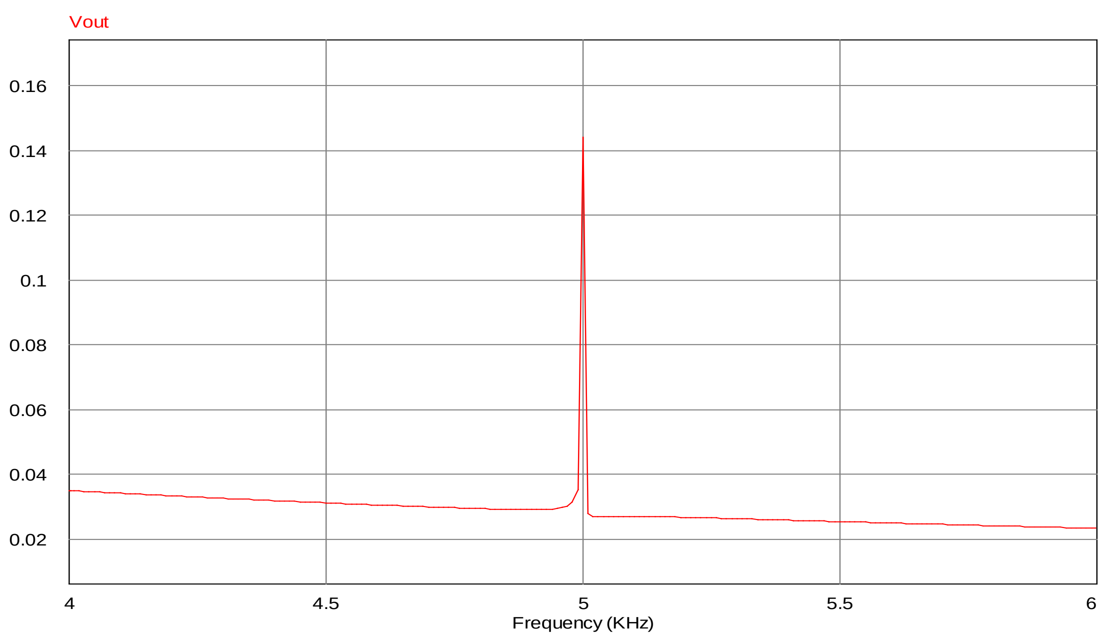


Figure 4.2.4: Fourier Transform

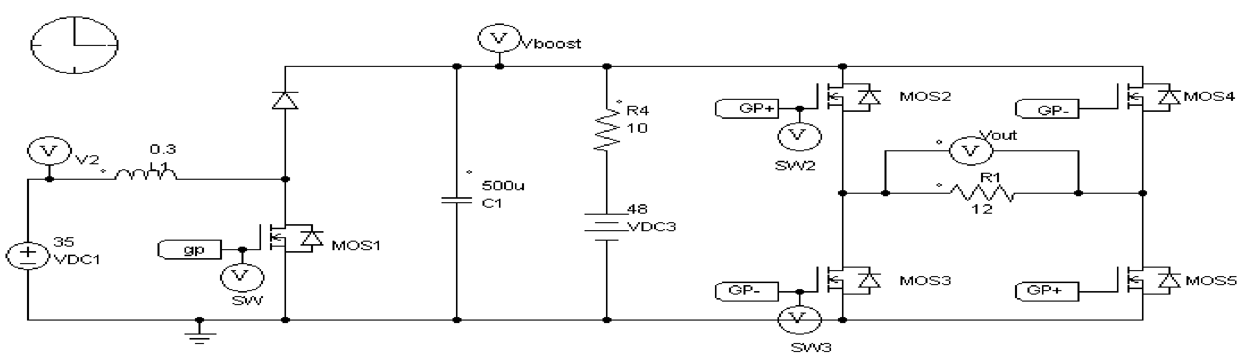
Chapter 5

Integrating Boost converter with Inverter

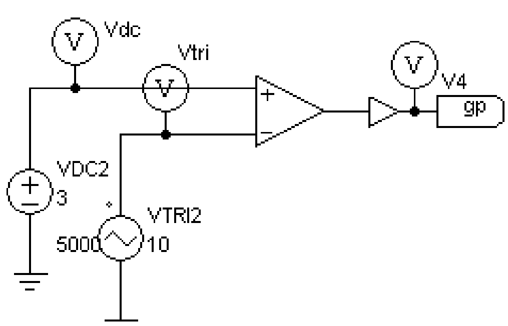
5.1 Introduction:

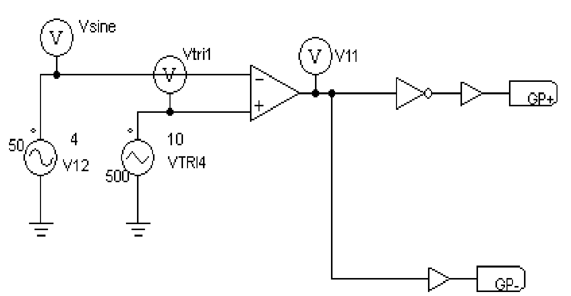
The circuit of Combining boost converter with inverter is shown in figure below, here the fundamental frequency is 50Hz and the triangular frequency is assumed 500hz (10times larger than fundamental frequency). We give gate pulses individually to the switches to run both boost and inverter circuit. Switching signals for both switches and output across load is given in the diagram below. We also analyze the switching frequency by Fourier transform (FFT).

5.2 Circuit analysis:



(a)





(b) **(c)**

Figure 5.1: Integration of Boost converter and Inverter circuit (a), gate pulse for sw (b), gate pulse (gp+) for sw2 and gate pulse (gp-) for sw3 (c)

5.2.3 Output of the System:

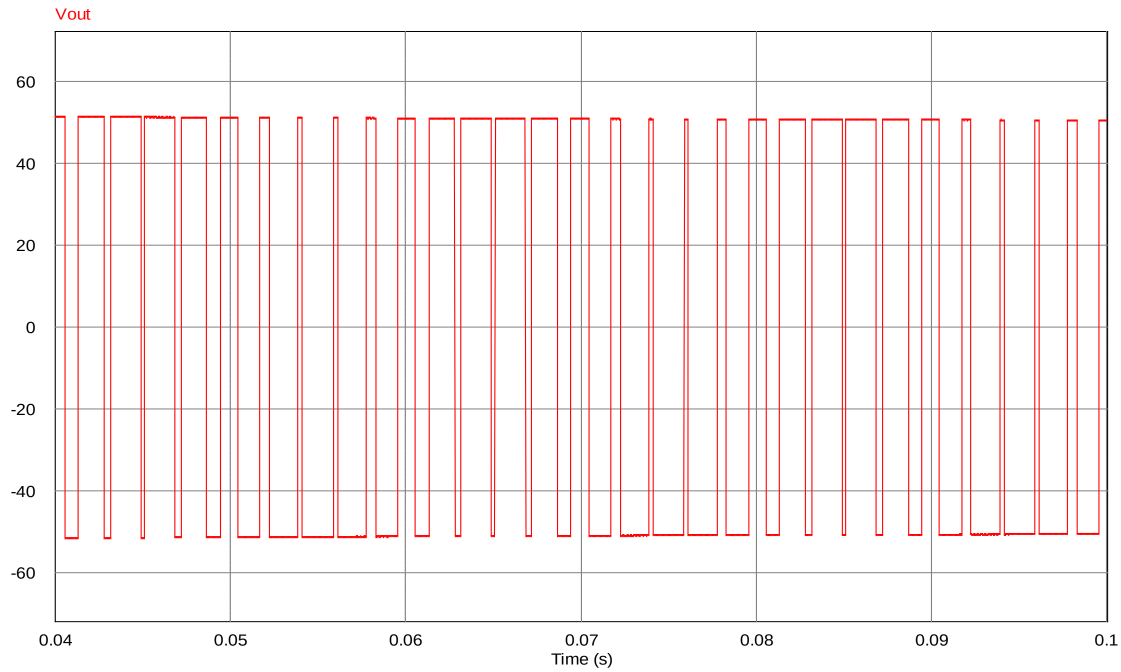


Figure 5.1.1: A typical output waveform of circuit 5.1(a)

5.2.4 FFT analysis:

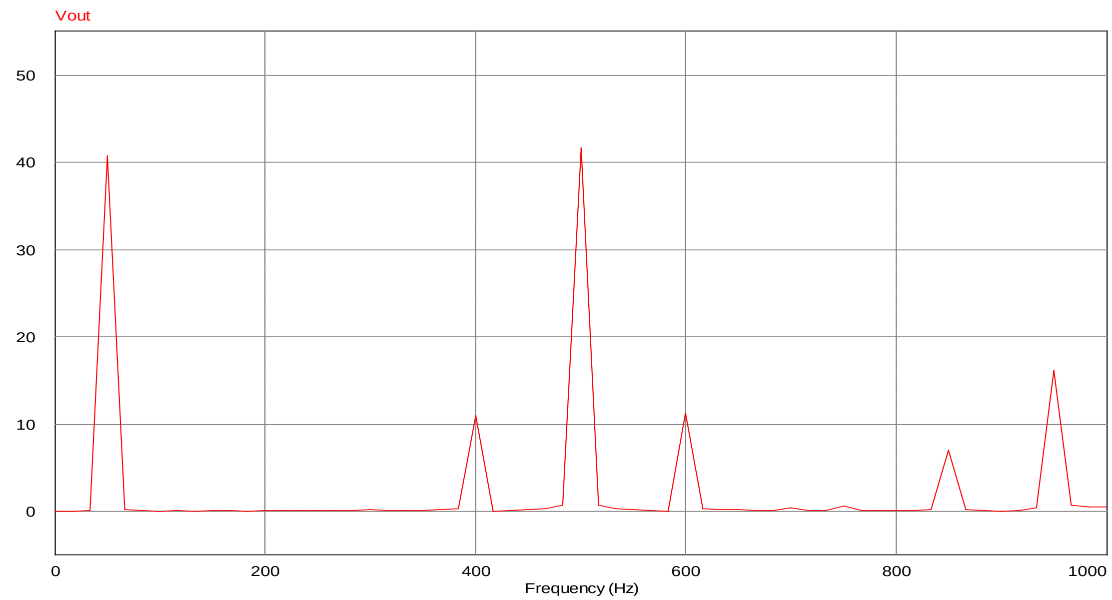


Figure 5.1.2: Fourier Transform

5.2.5 FFT analysis with frequency 30k:

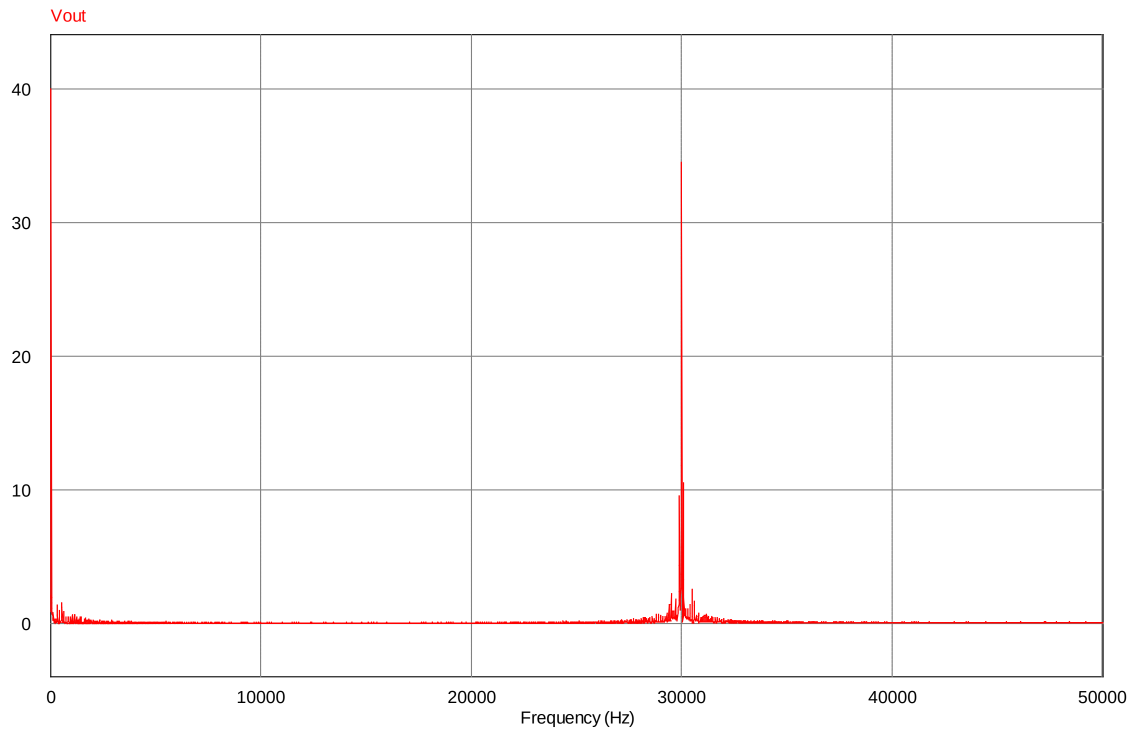
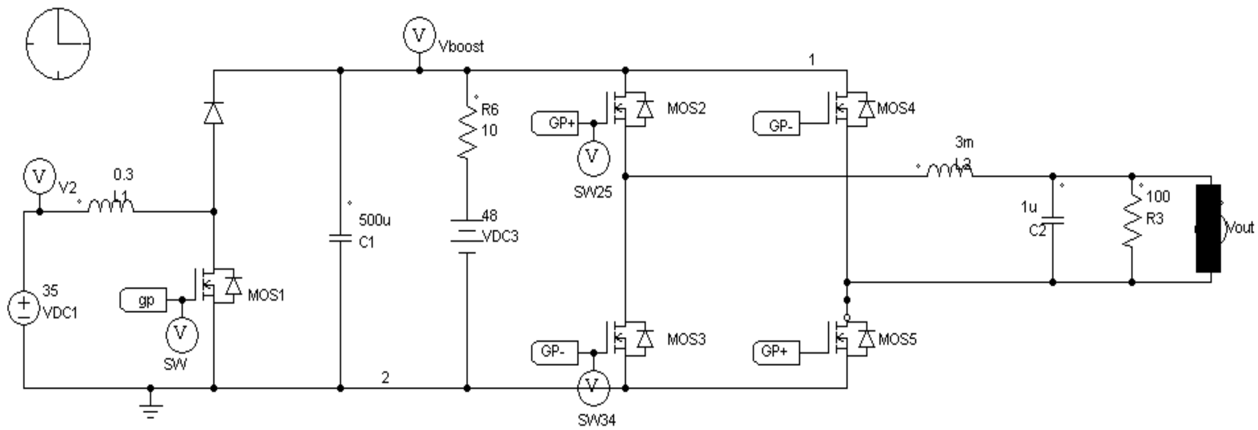


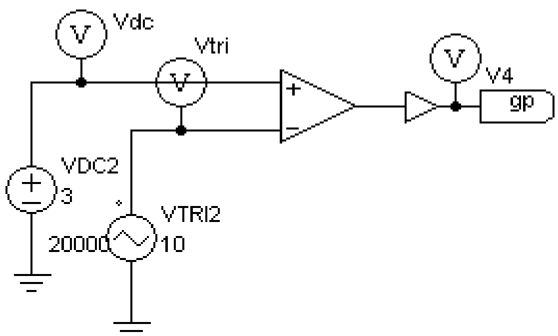
Figure 5.1.3: Fourier Transform for 30 kHz

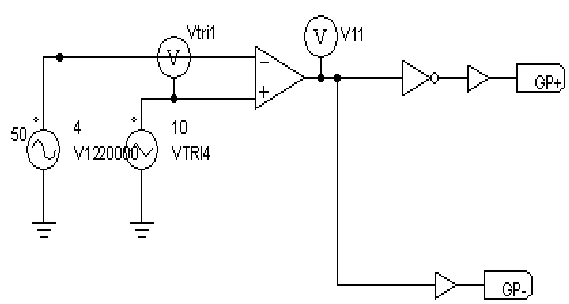
5.3 Circuit analysis with Low Pass Filter after output:

We use a low pass filter after the output of inverter (using Figure: 5.1) to generate sine wave from square wave, for high frequency like 30kHz filter size will be small, so inductor and capacitor value will be low. A circuit with LPF is shown below where output is shown at 12k resistor. If we give the exact value of inductor and capacitor in low pass filter, we can get pure sine wave but here we use random values.



(a)





(b) **(c)**

Figure 5.4: Full circuit with Low pass filter (a), switching signal for boost converter (b), switching signal for inverter(c)

5.3.1 Output of the System:

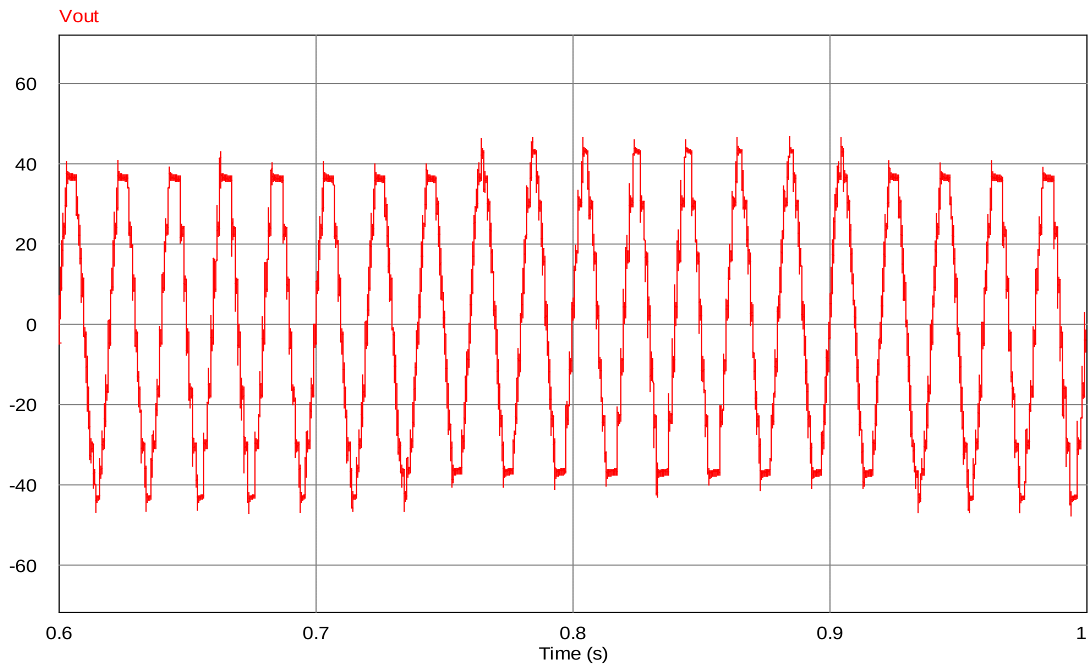


Figure 5.4.1: Output after using LPF

5.3.2 FFT analysis:

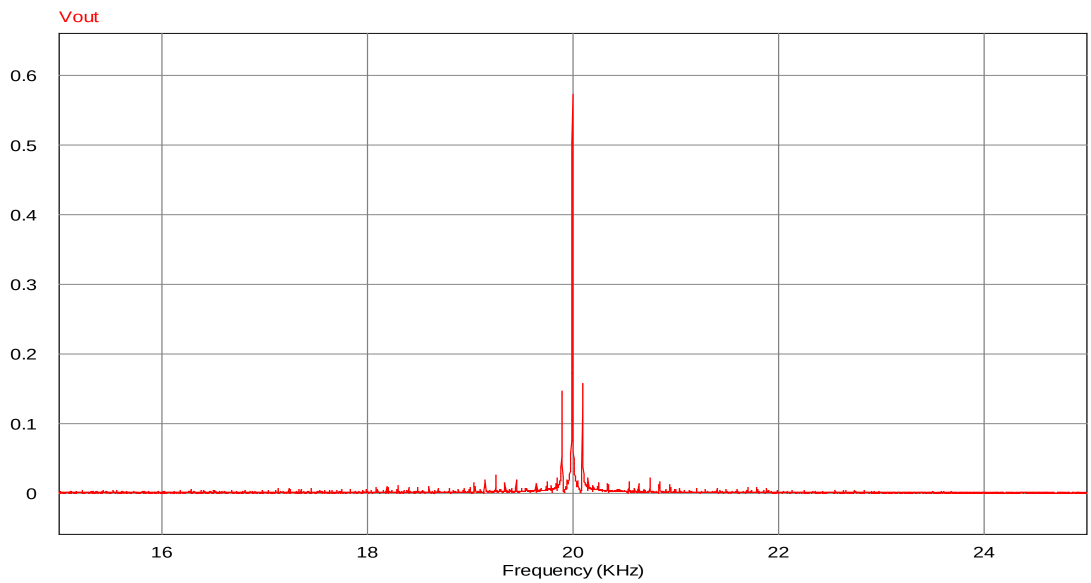


Figure 5.4.2: Fourier analysis

Chapter 6

Conclusion

6.1 Conclusion:

When we were constructing the whole system, we always keep in mind about efficiency and keeping power losses to a minimum level. This project is about to build up a PWM sine wave inverter but we also use boost(DC to DC) converter to step up the DC voltage and a low pass filter. We studied DC-AC converter, DC-DC converter both theoretically and experimentally. This whole system can be improved upon by using fuel cell stack (renewable energy) technology in parallel with battery in 3rd world countries. To deliver high voltage to load we can use a step up transformer after low pass filter (LPF).

References:

1. POWER QUALITY by C. SANKARAN, CRC PRESS, Florida, 2002
2. The Power Electronics Handbook, Uninterruptible Power Supply (chapter 16) by Laura Steffek, John Hecklesmiller, Dave Layden, Brian Young.
3. Technical Comparison of On-line vs. Line-interactive UPS designs By Jeffrey Samstad Michael Hoff.
4. http://ecmweb.com/content/rounding-rotary-ups-features
5. http://www.criticalpowersupplies.co.uk/Different-types-of-UPS-applications
6. http://www.pressroom.ups.com/Fact+Sheets/ci.UPS+Uses+Technology+and+Operational+Efficiencies+to+Reduce+Fuel+Consumption+and+Emissions.print
7. http://homemadecircuitsandschematics.blogspot.com/2012/05/discussing-advantages-of-mosfets-for.html
8. Power Electronics (chapter 08) by Daniel W. Hart Valparaiso University, Valparaiso, Indiana
9. http://en.wikipedia.org/wiki/Boost_converter
10. A PEMFC/Battery Hybrid UPS System for Backup and Emergency Power Applications Yuedong Zhan, Jianguo Zhu, YouguangGuo and Hua Wang Department of Automation, Kunming University of Science and Technology, Kunming, 650093,China
    Faculty of Engineering, University of Technology, Sydney (UTS), NSW 2007, Australia